INSTRUCTION BOOK

for

MODEL 321
TRUE RMS / AVERAGE / PEAK
ELECTRONIC VOLTMETER

STARTING WITH SERIAL No. 826

BALLANTINE LABORATORIES, INC.
BOONTON, NEW JERSEY

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BALLANTINE LABORATORIES, INC.
BOONTON, NEW JERSEY

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FOR
MODEL 321 TRUE RMS/AVERAGE/PEAK
ELECTRONIC VOLTMETER

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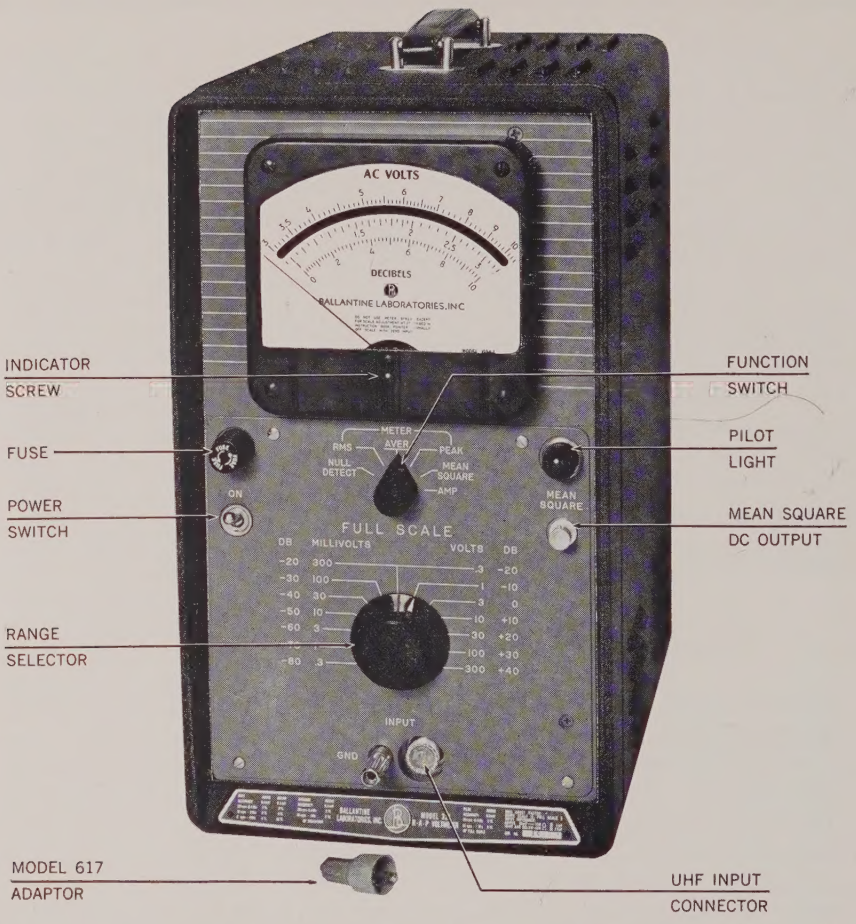


Fig. 1. Ballantine Model 321 True RMS/Average/Peak Electronic Voltmeter

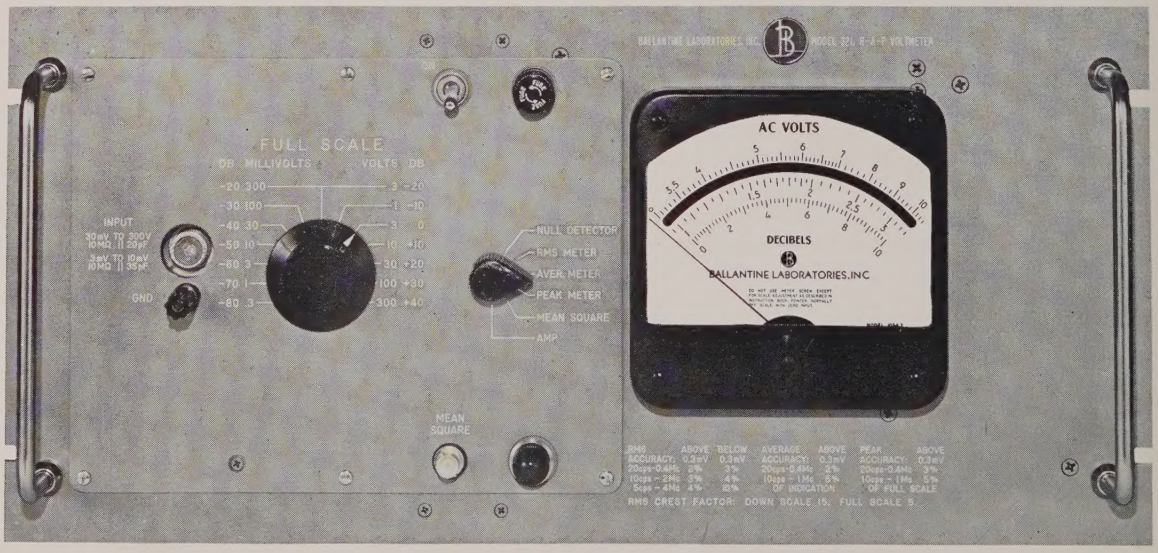


Fig. 2. Rack Panel Mounted Ballantine Model 321-S/2 True RMS/Average/Peak Electronic Voltmeter

1. GENERAL INFORMATION

1.1 Purpose and Use

The Ballantine Model 321 is a sensitive wide band ac voltmeter with three switch-selected responses. This voltmeter can be used to measure the root-mean-square, average and peak value of ac waveforms.

In RMS mode the voltmeter measures and displays the true rms value of the input ac waveform.

In AVERAGE mode the voltmeter measures and displays the average value of the input ac waveform.

In PEAK mode the voltmeter measures and displays the highest repetitive peak of the input ac waveform.

Its main characteristics — accuracy, bandwidth and maximum crest factor — are chosen so that the instrument is suitable for accurate measurement of a wide variety of complex waveforms which are encountered in current acoustical, vibrational, noise, pulse and magnetic measurements. Besides sinewaves it measures distorted waveforms, random noise and pulse trains with duty cycles as low as 0.04 and pulse widths as short as 0.3 μsec.

The true rms response of the Model 321 is achieved by means of the Ballantine patented square law detector which is an accurate, wide band, segmented function generator. In conjunction with a full wave rectifier, this detector provides a precise, wide dynamic range, and instantaneous squaring action which is unaffected by the normal range of ambient temperature, overload and component aging. The indication is achieved on two 4.5″ long, mirrorbacked, logarithmic scales. *The same precision and accuracy applies to measurements at any point on the scales.* In fact, higher accuracy specification at full scale indication is possible, but it is Ballantine's philosophy that specifying higher accuracy for only certain parts of the scale does not increase the usefulness of the voltmeter. An associated linear db scale with dbv (1 V) as reference is supplied with the standard instrument.

Average response is accomplished by connecting a low pass filter between the full wave rectifier and the square law network. The average voltage is displayed on the same two logarithmic scales.

For peak response a cathode follower is connected between the full wave rectifier and the square law network. Again, the same two logarithmic scales are used to display the measured voltage.

In the design of the voltmeter special consideration is given to operation under disturbing influences. The coaxial type UHF input terminal provides a low ground impedance input which reduces the error due to ground currents and allows the use of coaxial input for accurate high frequency measurements. A Model 617 adapter supplied with the voltmeter converts the coaxial input to standard ¾″ spacing binding posts, an input preferred for low frequency measurements. The warmup drift is kept small, so that the voltmeter is usable 20 sec after being turned on. The effect of line voltage transients is minimized so that the Model 321 may be used under very unfavorable line conditions.

Besides the excellent initial performance, great emphasis is placed on the reliability and life of the voltmeter. Because of the conservative loading of tubes and components, proper amount of feedback and the reserve in accuracy specifications, it is expected that the great majority of voltmeters will meet its specifications over 5,000 hours of normal laboratory use without the need for readjustments or recalibration. The voltmeter design is such that whenever a tube change may be necessary it does not influence the voltmeter performance over most of the useful band and does not require extensive recalibration or adjustment. The Model 321 stability against line voltage changes is such that the line voltage variation from 105 to 125 V will not set the instrument out of specifications. These features make the Model 321 a very economical instrument with respect to service and upkeep which, considering its low initial cost, adds more to the value of the voltmeter.

Beyond its basic function as a voltmeter, the Model 321 may be used as a null detector with a sensitivity down to 10 μV. It also can be used as a wide band amplifier with floating, grounded or symmetrical output. Up to 50 V rms may be obtained from the amplifier output. A dc current proportional to the mean square value of input voltage may be obtained, to drive a recorder or other readout device. By means of Ballantine series 600 calibrated shunts, the Model 321 may be converted to an ac ammeter with sensitivity down to 0.1 μA.

The construction of the voltmeter uses high grade printed wiring boards which guarantee uniformity and easy serviceability of the instrument. Modern frame grid tubes with highest grade components are used throughout the circuit. The design is based on 7 years experience with the Ballantine Model 320 — an accepted standard of rms voltmeters throughout the industry.

The Model 321 is available in portable or rack mounted version for 115 V or 230 V, 50 to 420 cps power line.

1.2 Some Applications of the Model 321

General voltage measurement in grounded circuits

Noise figure determination of tubes, transistors, networks and resistors

True rms vibration measurements, in conjunction with vibration pickup

White noise tests of audio equipment and noise level checks in wide band carrier and video systems

Mean square sound pressure measurement and acoustic studies with suitable microphones

As audio output power meter with appropriate load impedance

Measurement of total harmonic distortion in conjunction with a fundamental suppression filter

Measurement of peak break-through voltage of insulating material

Electrolysis studies using average voltages

Measurement of average voltages with large crest factors

1.3 Technical Characteristics

	RMS (Indicates True-rms)	AVERAGE (Indicates Average)	PEAK (Indicates Highest Repetitive Peak)
Voltage Range	100 μV — 330 V	300 μV — 330 V	300 μV — 330 V
As null detector	10 μV — 100 μV		
Frequency Range	5 cps — 4 Mc	10 cps — 1 Mc	10 cps — 1 Mc
3 db bandwidth	2 cps — 7 Mc		
Waveforms	Sine, distorted sine, complex, pulse, random	Sine, distorted sine, complex, pulse, random	Sine, distorted sine, repetitive pulses to 5 μs, having min duty cycle of 0.007; square wave response 100 cps - 400 kc
Crest Factor	15 down scale, 5 up scale; for pulse and flat waveforms crest factor is 10 down scale, 4 up scale	7 down scale, 4 up scale	
Accuracy above 300 μV	(See also Notes 1 and 2 below)		
20 cps - 0.4 Mc	2% of indication	2% of indication	3% f.s.d.
10 cps - 1. Mc	3% of indication	5% of indication	5% f.s.d.
10 cps - 2. Mc	3% of indication		
5 cps - 4. Mc	4% of indication		
Accuracy below 300 μV			
20 cps - 0.4 Mc	3% of indication		
10 cps - 2. Mc	4% of indication		
5 cps - 4. Mc	10% of indication		
Expected Calibration Stability	5000 hours	5000 hours	1000 hours
Effect of Ambient Temperature, 20°C to 30°C	< 1/10 stated accuracy	< 1/10 stated accuracy	< 1/2 stated accuracy

Effect of Line Voltage Change — Change of 10% from nominal line voltage of 115/230 V affects stated accuracy by less than 1/10

Input Impedance — 10 MΩ parallel with 11 pF, 30 mV - 330 V; 10 MΩ parallel with 27 pF, 0.3 mV - 10 mV

Equivalent Input Noise — Input shorted, 20 μV max; input open, 40 μV max

Scales — Voltage 0.95 to 3.3 and 3.0 to 10.6, logarithmic; decibels, 0 - 10 linear

Decibel Range — −80 to +40 db referred to 1 V

Response Time — Indicator 1 to 2 s; mean square output 0.05 s

Amplifier — Output on binding posts in rear, balanced or single-ended; max gain 90 db, adjustable in 10 db steps with range selector; intermediate values may be read on db scale; max output 50 V into 20,000 Ω; 10 V into 2,000 Ω; source impedance 350 Ω at 1 kc; frequency response ±0.5 db from 5 cps to 2 Mc, —1 db at 4 Mc, with 25 pF maximum capacitive loading

Mean Square DC — Output on front panel BNC receptacle; output is −0.2 V corresponding to full scale deflection; max output is −1.0 V; source resistance is 1,000 Ω

Power Supply — 115/230 V, 50 to 420 cps, 90 W

Vacuum Tubes and Semiconductors

Tubes

2 — 5654 1 — 12B4A 1 — 5V4G
4 — 6EJ7 1 — OA2 1 — 5651
1 — 8223 or 1 — 6DJ8 1 — OB2

Semiconductors

10 — germanium diodes
1 — silicon diode
2 — silicon rectifiers

Dimensions (inches) — Portable 15⅛ H x 8⅛ W x 11¾ D; Rack 8 $^{23}/_{32}$ H x 19 W x 12¾ D

Weight (pounds) — Portable or rack, 22; shipping weight, portable 27 and rack 40

Color — Portable, gray panel and black case; rack, gray or special to order

Note 1 — Midband accuracy of "2% indication" is far more accurate over the lower half of the scale than an instrument rated at "1% of full scale deflection (f.s.d.)".

Note 2 — Logarithmic voltage scales assure uniform accuracy as well as uniform resolution over their entire five inches. No linear scale indicator has this very important feature.

2. OPERATION

2.1 Power Connection

The voltmeter is supplied ready to operate on 105 - 125 V, 50 cps - 420 cps or 210 - 250 V, 50 cps - 420 cps power line, as indicated on the decal mounted adjacent to the power cord.

2.1.1 Line Voltage Conversion from 115 V to 230 V or vice versa is possible. For conversion from 115 V operation to 230 V operation, connect the power transformer leads as follows:

Disconnect black-red lead from terminal 4 and black-yellow lead from terminal 6, and connect both together to terminal 5. Replace fuse F1 0.8 ampere by 0.5 ampere Slo-Blo fuse. Detailed information for 115 V/230 V conversion is given on the schematic at the end of this instruction book.

2.2 Starting Procedure

Insert the three prong plug into a proper ac power outlet. Use conversion unit where only two prong outlets are available. Move the power switch to ON position. The pilot light should glow. The instrument is ready for use after a short warmup period.

2.2.1 Warmup Period

The instrument is usable in RMS or AVERAGE mode after 20 seconds warmup. In PEAK mode the warmup should be extended to 5 minutes.
When the instrument has not been in use for many months or has been stored in high humidity allow a warmup period of at least one hour.

NO SOURCE OF HEAT SHOULD BE CLOSE TO THE BACK OF THE INSTRUMENT. PERMIT AIR TO CIRCULATE FREELY AROUND THE VOLTMETER TO AVOID EXCESSIVE TEMPERATURE RISE IN THE INSTRUMENT.

The voltmeter is calibrated in the vertical position. For convenience in reading, a tilting device is provided beneath the case.

2.3 Function of Controls (See Figure No. 1 for control locations)

Power Switch ON — Turns the instrument on.

Function Switch

NULL DETECT — The instrument operates as RMS indicator for voltages normally below the voltmeter scale.

RMS METER — Instrument indicates the RMS value of AC waveform.

AVER METER — Instrument indicates the average value of AC waveform.

PEAK METER — Instrument indicates the highest repetitive peak of AC waveform.

MEAN SQUARE — Instrument operates as an RMS ac to dc converter. The dc output proportional to the square of ac input voltage is available from MEAN SQUARE connector.

AMPLIFIER — The instrument operates as wide band amplifier with the output terminals at the rear of the case.

Range Selector

FULL SCALE
.3 to 300 mV
.3 to 300 V — Selects the voltage range in METER or NULL DETECT operating mode. Changes the amplifier gain in 10 db steps in AMPLIFIER mode, or dc mean square output in 20 db steps in MEAN SQUARE mode of operation.

2.3.1 Connectors and Terminals

INPUT — Type UHF connector for signal input. May be converted to binding posts with Ballantine Model 617 adapter.

GND — Ground binding post connected to the Voltmeter chassis and ground prong of the line cord.

MEAN SQUARE — Type BNC connector for dc output in MEAN SQUARE mode of operation.

AMP OUTPUT — Four binding posts for floating, symmetrical or single ended amplifier output in AMPLIFIER mode of operation.

2.3.2 Controls — adjustable by screwdriver through the holes in the rear of the voltmeter:

LIN ADJ — Adjust electrically the down scale sensitivity in RMS METER and MEAN SQUARE mode of operation.

NULL ADJ — Adjust the rest position of the pointer in NULL DETECT mode of operation.

SENS ADJ — Adjust the instrument sensitivity in RMS METER, NULL DETECT and MEAN SQUARE modes of operation.

— adjustable by screwdriver on the left side of the voltmeter (after case is removed):

AVER ADJ — R120 adjusts the sensitivity of average response.

PEAK ADJ R127 adjusts the sensitivity of peak response.

PEAK LIN R123 adjusts the linearity of down scale indication in PEAK mode.

PEAK COMP R124 adjusts the compensation for power line voltage effect in PEAK mode.

— adjustable at the front of the instrument:

Indicator Screw

Adjust the down scale indication in METER modes of operation.

2.4 Voltage Measurement

For ac voltage measurement:

Set	To
Function Switch	RMS METER, AVER METER, or PEAK METER
Range Selector	300 V

Connect the unknown voltage to the input and rotate the range selector counterclockwise until indication appears on the meter scale. Take reading from the scale indicated by the range selector. If the indication is down scale, below the read db scale, select the next lower voltage range to bring the indication close to full scale for best readability. Because of the logarithmic meter scale and Ballantine special design, the *accuracy of the measurement is the same at any point on the scale* for rms and average measurements. Peak measurement accuracy is specified in terms of % of full scale. With a logarithmic scale indicator the pointer rest position is normally off scale.

At approximately every 200 operating hours or when the measurement with utmost accuracy is desired, check the scale adjustment and PEAK LIN adjustment.

2.4.1 Scale Adjustment checks the scale linearity of the logarithmic indicator. It is equivalent to the zero adjustment in linear meter. For scale adjustment,

Set	To
Function Switch	RMS METER
Range Selector	1 V

Apply a stable 100 cps to 10 kc signal to the input. Adjust the amplitude to give an indication exactly on 10 on upper voltage scale. Rotate range selector to 3 V range. If the indication is not at 1.0 of lower voltage scale adjust the meter screw at lower center of the meter face until indication is 1.0 $\pm 0.2\%$. Repeat the procedure until full scale indication on 1 V range agrees exactly with down scale indication on 3 V range.
Do not use the meter screw to bring the pointer on marked scale when no signal is applied to the voltmeter.

2.5 Possible Error Sources

The causes of some obvious measuring difficulties are listed below:

2.5.1 Pointer Stays Extreme Left when no signal is applied to the input, voltmeter is turned off or not connected to the power line, the input voltage is lower than the range selected, function switch is on MEAN SQUARE or AMPLIFIER position.

2.5.2 Indication Is High and the pointer stays on scale even after the next higher voltage range is selected. This happens when the function switch is in NULL DETECT position.

2.5.3 Pointer Stays Extreme Right when selected voltage range is too low or high hum is picked up by input circuitry.

Because of the wide frequency range and high sensitivity of the Model 321, other measuring errors may be introduced when proper measuring techniques are not used. The most common error sources are listed below. A more comprehensive analysis of errors is given in NBS Conference on Standards and Electronic Measurement paper: Techniques and Errors in High Frequency Voltage Calibration by Dr. E. Uiga and W. F. White. A copy of the paper is available from Ballantine Laboratories without charge.

2.5.4 Input Impedance and Loading Error

The input impedance of the Model 321 depends on the setting of the Range Selector and the frequency of the signal measured. It may be represented with a parallel combination of input capacitance and resistance.

The input capacitance is 27 pF for ranges .3 mV to 10 mV and 11 pF for ranges 30 mV to 300 V. The variation of input capacitance with signal frequency is small.

The input resistance is 10 MΩ at low frequency. It changes with frequency as indicated in figure 3.

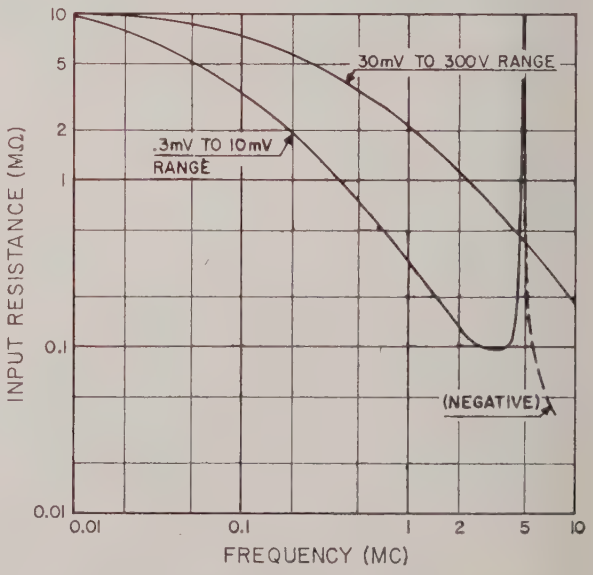


Fig. 3. Input Resistance Change with Frequency

As seen from the graph the input impedance on 0.3 mV to 10 mV ranges is negative at frequencies above 5Mc. This may cause an undamped resonance circuit tuned to 5 - 10 Mc to oscillate when voltmeter is connected across it. When that occurs, connect a parallel resistor with value equal to the negative resistance of input impedance across the input of the voltmeter.

The effect of the voltmeter input impedance and the impedance of the connecting leads is to load, damp or detune the circuit. This should be considered when high impedance sources above 100 kΩ or tuned circuits are measured.

2.5.5 Ground Current Error is caused by the ground currents of signal or power line frequency which may flow through the ground connection. This current develops a voltage drop in ground connection. This is measured together with the signal. To reduce this effect the ground current should be kept minimum and the ground impedance kept as low as possible. The existence of the ground currents may be determined by measuring the ground lead current with an ammeter or clip-on current probe. To reduce the ground current connect all the equipment in the setup to the ground at one point, use insulation transformers or connect a several hundred ohm resistor in series with the ground prong of the power cord. This can easily be accomplished by using a 3 to 2 prong cord adapter and connecting the resistor in series with the ground wire from the adapter.

The impedance of ground connection may be made smaller by using as short a ground lead as possible. Model 321 has a coaxial input which provides a low ground impedance. Use this coaxial input for measurement above 1 Mc wherever possible. For low frequency measurement the input may be converted to binding posts using Model 617 adapter.

2.5.6 Transmission Line Error is caused by transmission line effect in unmatched input leads. When 50 Ω cable is used this effect should be considered when measuring above 3 Mc and when line length exceeds 3 ft.

2.5.7 Magnetic and Electrostatic Fields may cause pickup in the input leads or induce disturbances into the sensitive parts of the voltmeter. To reduce this effect use coaxial, shielded twisted or closely spaced input leads. Do not place the voltmeter close to strong sources of magnetic or electromagnetic fields. The most sensitive part of the voltmeter is the lower right corner where the input circuitry is located.

2.6 Use of the DB Scale

The db scale on Model 321 is based on dbv (1 mW into 1000 Ω) reference. To determine the dbv level, add the db indication from the red db scale to the db figure indicated on Range Selector. The dbv level may be converted to other reference levels by using conversion figures shown in Table I.

TABLE I

DB LEVEL CONVERSION	
Conversion from dbv (1 mW/1000 ohms)	**Reference Level**
add 2.2 db	0.775 V, 1 mW in 600 Ω (dbm)
subtract 4.8 db	1.732 V, 6 mW in 500 Ω
subtract 5.6 db	1.897 V, 6 mW in 600 Ω

To simplify the conversion and to compute db levels of other references a handy db slide rule is available from Ballantine Laboratories on request, free of charge.

2.7 Effect of Harmonics

In case of complex waveforms with several harmonics the Model 321 measures the true rms voltage independent of the phase relationship of the harmonics.

$$E_{rms} = \sqrt{E_1^2 + E_2^2 + E_3^2 + \ldots + E_k^2} \qquad (1)$$

E_{rms} — rms amplitude of the complete waveform

E_1 — rms amplitude of fundamental frequency component

E_2, E_3 — rms amplitude of harmonic frequency components

When some of the harmonic frequencies are beyond the voltmeter's frequency range or fall into less accurate range, their effect may be calculated by using the equation (1).

The voltmeter response, although not calibrated, extends above the specified 4 Mc limit. Except on the 0.3 mV range, the response is down approximately 1.5 db at 6 Mc and 3 db at 7 Mc.

The use of the equation (1) is illustrated with the following example:

Example:

A 500 kc square wave with the rms amplitude of 1.000 V is measured. To achieve an accuracy of 0.1% the harmonics up to 51 harmonics with maximum frequency of 25.5 Mc, should be measured. When the Model 321 is used for measurement, the bandwidth is limited to 7 Mc or to 13th harmonic. Under those conditions the result would be 0.989 V or an error of 1.1%.

To illustrate the effect of reduced accuracy for different harmonics, an assumption is made that the Model 321 used for measurement has the maximum negative error allowed by specification, as shown in Table II.

TABLE II

MAXIMUM CORRECTION FOR HARMONICS	
Harmonic	**Error**
1.5 Mc (3rd harm)	—3%
2.5 Mc (5th harm)	—3%
3.5 Mc (7th harm)	—5%
4.5 Mc (9th harm)	—5%
5.5 Mc (11th harm)	—10%
6.5 Mc (13th harm)	—30%

This assumption is not realistic because the voltmeter normally has positive and negative errors which tend to compensate one another. Using the formula for this hypothetical case, the result would be 0.984 V or an error of 1.6% or only 0.5% less than when measured with flat response instrument.

As a conclusion, the measuring accuracy is determined mostly by the accuracy of fundamental frequency or harmonics which have the highest energy contents. The harmonics with lesser energy contents have a small effect proportional to their energy contents (square of the amplitude). The effect may be calculated using equation (1) by considering only the harmonics which fall into the passband of the voltmeter and/or by assigning the harmonics amplitudes corrected by the known error of the voltmeter.

2.8 Effect of High Crest Factor

The Model 321 measures with specified accuracy any complex waveform with the maximum crest factor (ratio of peak and rms amplitude) — 15 for a down scale indication — decreasing proportionally to a maximum 5 for full scale indication.

The crest factor may exceed those limits without affecting measuring accuracy if the following conditions are fulfilled:

a) the peaks occur only occasionally

b) the maximum crest factor of the peaks does not exceed 8 (fs) to 25 (ds)

c) the peaks have sharp or rounded tops

Higher crest factor than 8 (fs) to 25 (ds) always causes high error because of amplifier overload.

When measuring the average value of a low duty cycle pulse train, overloading of the amplifiers should be avoided.

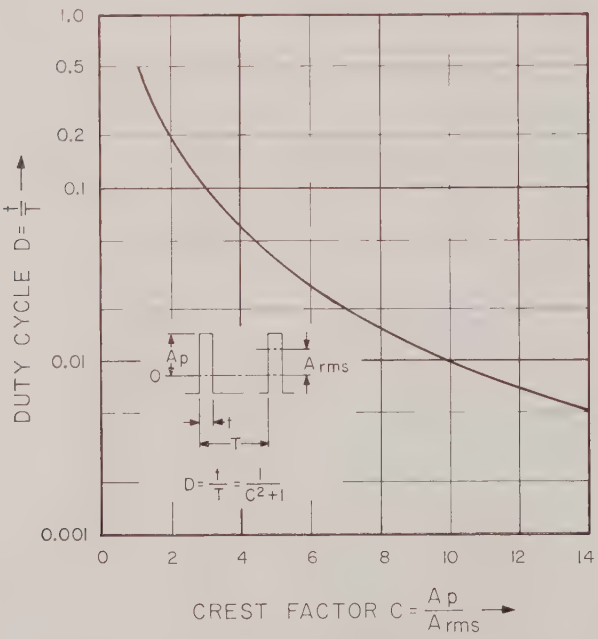


Fig. 4. Duty Cycle and Crest Factor of a Pulse Train

Therefore the crest factor is limted to 7 at bottom scale and decreases to 4 at full scale.

When measuring the peak value, there is no danger of overloading the amplifiers.

2.8.1 Flat Top Waveforms (pulses) with crest factor of more than 4 (fs) to 10 (ds) cause negative errors, which may be as high as —2% for maximum crest factor 5 (fs) to 15 (ds). The error will increase rapidly with higher crest factor pulses, and the use of the voltmeter is not recommended.

The relationship of the crest factor to the duty cycles of a pulse train is shown in figure 4.

2.9 Effect of the DC Component

The Model 321 is ac coupled and responds only to the ac component of a waveform. If a dc component is present, it should be measured separately. If an unsymmetrical waveform which contains a dc component has to be measured, measure the dc component separately with a dc voltmeter and compute the true rms value by the equation (2):

$$E_{rms} = \sqrt{E_{dc}^2 + E_{ac}^2} \qquad (2)$$

Example:

1 V dc is chopped into square pulses with 1 V peak amplitude. This pulse train has a dc component of 0.5 V which will be measured if the waveform is fed into a dc voltmeter.

The ac component of the waveform is a 0.5 V amplitude square wave with rms value 0.5 V which will be measured when the Model 321 is used.

The total rms value of the waveform is

$$E_{rms} = \sqrt{E_{dc}^2 + E_{ac}^2} = \sqrt{0.5^2 + 0.5^2} = 0.707 \text{ V}$$

which will be measured with thermocouple-type instruments which respond both to ac and dc components.

The dc component of the waveforms is blocked by the input capacitor which has a 600 V dc rating. When more than 600 V dc is superimposed on the ac voltage, use an external 0.1 μF or higher blocking capacitor with proper dc rating and connect a 20 MΩ resistor to the input as shown in figure 5.

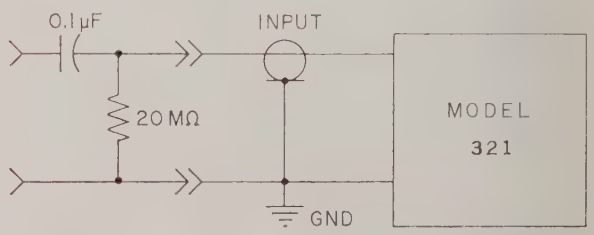


Fig. 5. Connection of the External Blocking Capacitor

2.10 Measurement of Noise and Random Signals

On noise and random signal measurement an error may be introduced by the limited bandwidth and by the limit of

maximum crest factor. In case of white noise, the rms value of the noise voltage E_{rms} depends on the bandwidth:

$$E_{rms} = K \sqrt{\Delta f} \qquad (3)$$

Δf — noise bandwidth (cps)

K — factor depending on the source

If the bandwidth of noise source is wider than the bandwidth of Model 321 an error in noise measurement is introduced. This error may be calculated from the equation (3).

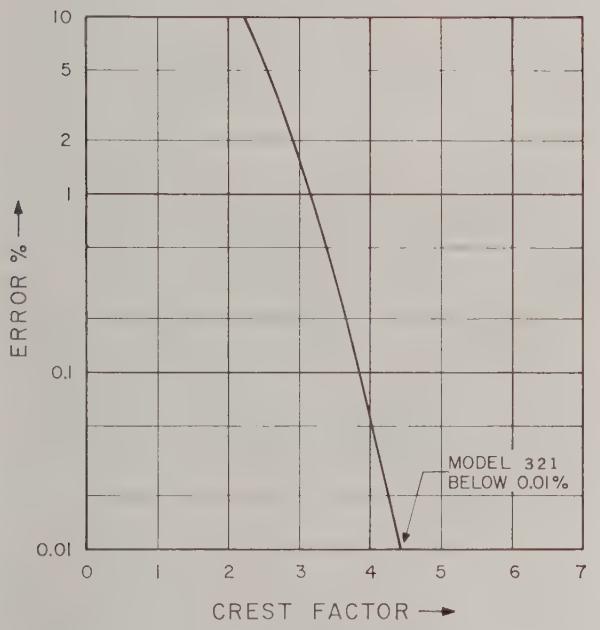


Fig. 6. Crest Factor Error with White Noise

For wide band noise measurement, 7 Mc may be considered as maximum bandwidth.

The crest factor limit also introduces an error. When measuring noise or random occurrences with Gaussian amplitude distribution, this error is depicted in figure 6. In the case of the Model 321 the crest factor limit of 5 introduces less than 0.01% error, which is negligible. However, when some circuit elements or preamplifiers introduce a more severe limitation of crest factor, the error should be considered when maximum crest factor limit approaches 3.5.

2.11 Measurement of Waveforms with Higher Crest Factor than 5

Waveforms up to crest factor 10 may be measured when the indication is limited to the lower half of the scale. To accomplish this, the input signal may be attenuated by a factor of 2 every time the indication comes to the upper half of the scale. An external attenuator, connected in front of the voltmeter, as shown on figure 7, may be used.

When the unknown voltage produces an indication on lower part of the scale, measure with switch in X1 position and read directly from scale. When indication falls in the upper part of the scale, set switch to X2 position and multiply the indication by 2. Match the attenuator resistors to 0.1%. Select value depending on loading restriction, to the source.

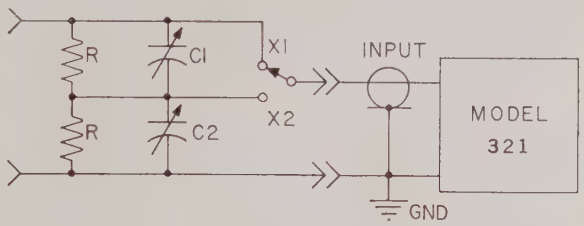


Fig. 7. Use of External Attenuator to Extend the Crest Factor Limit

In case of high values (above 1000 Ω) and when measuring high frequencies, the attenuator should be compensated by capacitors C1 and C2. These should be adjusted to the accurate 2 to 1 attenuation ratios at high frequency.
A ratio transformer may be used for low frequency measurements.

2.12 RMS Measurement on .3 mV Range

The effect of 24 μV internal noise level is negligible on all ranges except in 0.1 mV to 0.3 mV range. In this range it causes approximately +3% error for 0.1 mV signal and 0.3% error for 0.3 mV signal. Because of the noise and reduction of amplifier feedback, the accuracy of measurement in the 0.3 mV range is reduced. The effect of noise can be corrected, reducing the indication by the amounts shown in Table III.

TABLE III

CORRECTIONS ON 0.3 mV RANGE
3% for 0.09 mV to 0.11 mV indication
2% for 0.11 mV to 0.14 mV indication
1% for 0.14 mV to 0.2 mV indication
0.5% for 0.2 mV to 0.31 mV indication

Because of the reduced feedback, the falloff at the band ends is more rapid than on the other ranges. The limits for crest factor are the same as for all other ranges.

2.13 Measurement of Voltages Above 300 V

Voltages from 30 V to 10 kV may be measured with the Model 1320 plug-in multiplier. This multiplier has a multiplication ratio of 100 and has an input resistance of 40 MΩ in parallel with 3 pF. The multiplier is usable from 5 cps to 1 Mc and causes an additional measurement uncertainty of ±2%.

Voltages from 1 V to 10 kV may be measured with the Model 1311 High Voltage Probe. This probe has a multiplication ratio of 10,000 and an input resistance > 10,000 MΩ in parallel with 4.5 pF. The probe and Model 321 are usable from 8 cps to 1 Mc with an additional measurement uncertainty of ±1%.

2.14 Use as Null Detector

In the null detector mode, the voltmeter may be used for approximate measurements and nulling of voltages normally below the scale.

2.14.1 To Use the Model 321 as Null Detector

Set	To
Function Switch	NULL DETECT
Range Selector	Any Range

Now the pointer's rest position is moved from against the left hand stop to the lower part of the scale so that small changes in deflection can be observed. The lowest observable voltage change in 0.3 mV range is 1 to 2 μV. Therefore a null may be observed with very high precision.

2.14.2 For Approximate RMS Voltage Measurements Below 100 μV

Set	To
Function Switch	NULL DETECT
Range Selector	0.3 mV

Short the input, adjust the NULL ADJ on the rear until pointer indicates 0 db on red scale. Apply voltage to the input and observe the indication. Use figure 8 to convert the indication to input voltage.

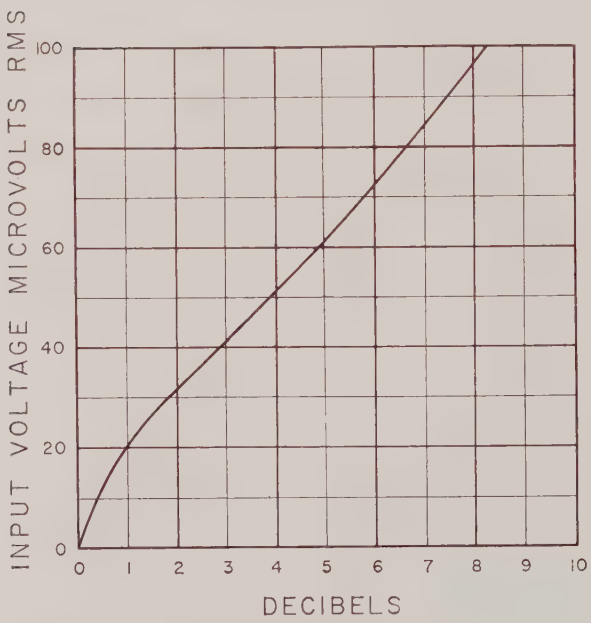


Fig. 8. Calibration of 0.3 mV Range on Null Detector Mode

The frequency response in Null Detector mode is the same as in RMS METER mode. The amplitude response deviates slightly from true rms. A small pointer jitter, caused by the noise of the voltmeter, is normal. Return Function Switch to RMS METER position after finishing the measurement. This will avoid possible errors in subsequent use as voltmeter, when the position of Function Switch may be overlooked.

2:15 Overload Characteristics

The safe overload limits for extended periods are

Range	Max Voltage
0.3 to 10 mV	35 V
30 mV to 300 V	350 V

For a shorter period higher overloads up to 300 V on the most sensitive range will cause no damage.

2.16 Influence of Power Line Voltage

The Model 321 is operative over a 90 V to 130 V (180 V - 260 V) line voltage and 50 cps to 420 cps line frequency range. For $\pm 10\%$ variation of line voltage from 115 V (230 V) nominal voltage, the typical change in voltmeter sensitivity is given in Table IV.

TABLE IV

EFFECT OF $\pm 10\%$ LINE VOLTAGE CHANGE			
Mode	**Frequency**	**1 mV - 300 V FS**	**0.3 mV FS**
RMS	20 cps - 1 Mc	$\pm 0.2\%$ MAX	$\pm 0.3\%$ MAX
	5 cps - 4 Mc	$\pm 0.5\%$	$\pm 1.0\%$
AVER	20 cps - 1 Mc	$\pm 0.2\%$	
	10 cps - 20 cps	$\pm 0.5\%$	
PEAK	10 cps - 1 Mc	$\pm 0.5\%$ AT FS	
		$\pm 1.5\%$ AT BS	

In null detector mode the pointer rest position is slightly affected by line voltage, readjust for accurate measurements.

2.17 RMS Current Measurements

The Model 321 may be used together with resistances of known value for making current measurements. The Ballantine Model 600 series of precision wirewound shunt resistors is recommended for this purpose. These resistors are available in the values of 0.01, 0.1, 1, 10, 100 and 1000 ohms and are supplied in plug-in form for insertion across the INPUT terminals. With these resistors, current of from 0.1 microamperes to 10 amperes can be measured. The crest factor limit is the same as for voltage measurement. Frequency range is dependent on the shunt used.

2.18 Power Dissipation Measurement

Because of the true rms response, the Model 321 may be used in power dissipation measurements in a pure resistive load. A voltage E (V) across a resistor R (Ω) dissipates

$$P = \frac{E^2}{R} \quad (W) \qquad (4)$$

Across a 600 Ω resistor the Model 321 measures dissipation from 16.7×10^{-12} to 180 W. This corresponds to 10^{13} power ratio or 130 db. DB ratio could be read directly from

the db scale of the voltmeter. To convert that to standard reference level, such as dbm or other, use constants listed on Table I.

2.19 Use of Mean Square Output

Model 321 may be used as a squaring ac to dc converter. For this mode,

Set	To
Function Switch	MEAN SQUARE
Range Selector	According to the Input Voltage

On any range, the input voltage which produces a full scale deflection in voltmeter mode of operation produces a −0.2 V output. This changes proportional to the square of input voltage. The source resistance of output is 1000 Ω in parallel with 50 μF. The output follows the square law to a maximum instantaneous input amplitude of 5 times the full scale deflection. The maximum dc output is −1.0 V.

With higher than 0.2 V output, the approximation of the square law has a negative error depending on the waveform.

A closer approximation of square law over a wider range of input voltage is possible when the R76 1 kΩ resistor is changed to lower value. This change will proportionally decrease the output voltage.

The dc output reaches 90% of its final value in 0.1 second. The ripple on dc output is negligible at 1 kc and 50% at 5 cps. Longer or shorter response or averaging times can be achieved by changing the value of C56 50 μF capacitor. This will also decrease or increase the ripple. Use tantalytic capacitors with minimum voltage rating of 6 V.

In case a low resistance recorder or external indicator is connected to MEAN SQUARE output, the load resistor R76 may be disconnected. The current output from MEAN SQUARE connector is −200 μA ±10% corresponding to full scale indication. Maximum available current is −2 mA.

The external device connected to MEAN SQUARE output should not apply any dc voltage to the output. This will affect the accuracy of square law.

2.20 Use as Amplifier

The voltmeter may be used as a stable, wide band amplifier.

Set	To
Function Switch	AMPLIFIER
Range Selector	According to the Input Voltage or Desired Gain
Output	Binding Posts at Rear

The maximum gain is 90 db ±1 db bandwith 5 cps to 4 Mc. Range Selector reduces the gain in 10 db steps until the lowest gain of −30 db on 300 V range.

The amplifier has a balanced transformer output which can be used floating, single-ended, or center tap grounded. For wide band operation ground the center tap.

The output from the output terminal marked IN PHASE is in phase with the input voltage. Voltage on REVERSE terminal has 180° phase shift with respect to input voltage.

The output voltage between IN PHASE and REVERSE terminals is 10 V when a signal which produces a full scale deflection in voltmeter mode is applied to the input.

The maximum distortion-free output signal is 50 V, for frequencies 30 cps to 500 kc. Outside this band the maximum available output voltage decreases to 10 V at 5 cps and 4 Mc. The voltage and gain between CT and IN PHASE or REVERSE terminals is 6 db less than the figures given above.

The source impedance at midfrequency is approximately 170 Ω from CT to IN PHASE or REVERSE terminal or 340 Ω from REVERSE to IN PHASE terminal. Between IN PHASE and REVERSE terminal the minimum allowable load resistance for 50 V maximum output is 20 kΩ, for 10 V maximum output 2 kΩ. The minimum loading resistor across half of the transformer output can be one-half of that value. Capacitive loading should be limited to 25 pF.

A maximum +300 V or −100 V dc can be applied between output transformer winding and chassis without causing damage.

3. CIRCUIT DESCRIPTION

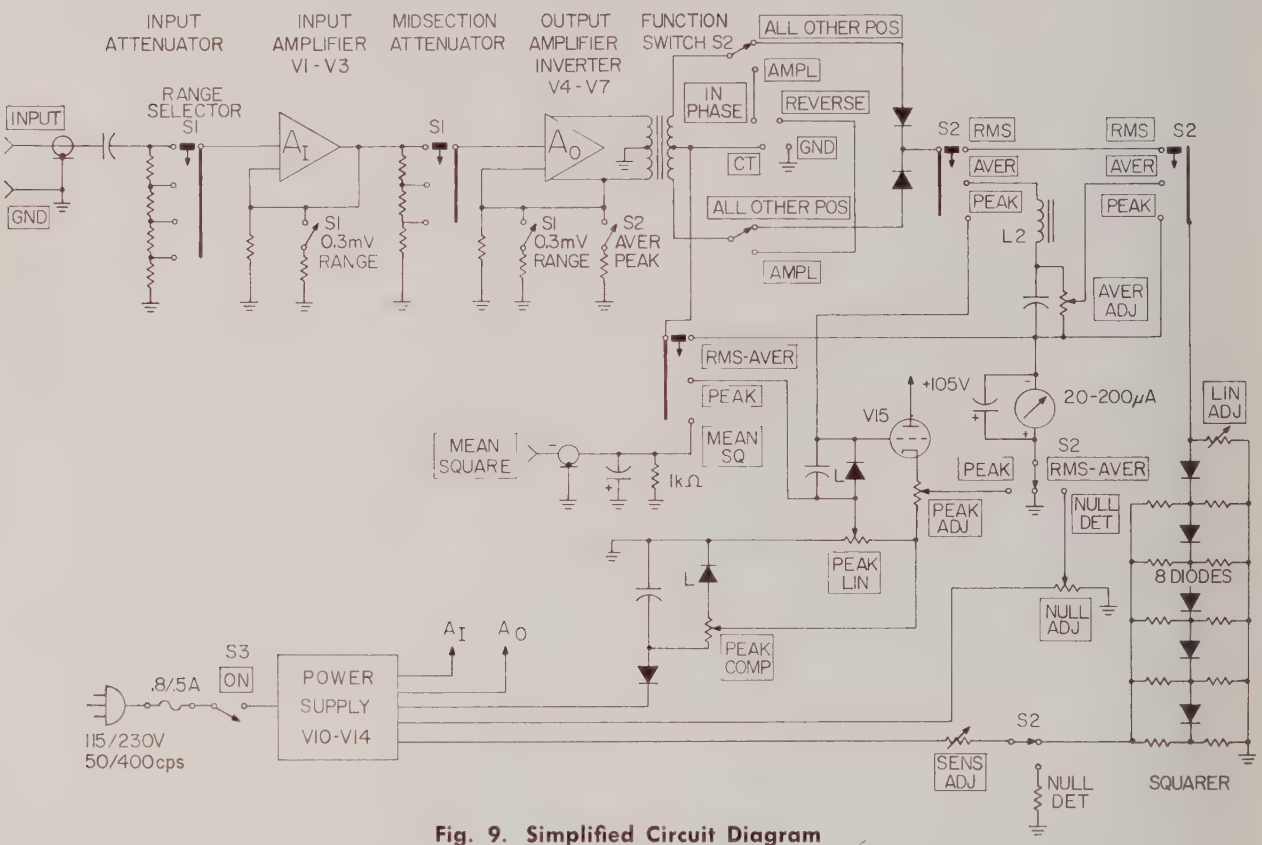


Fig. 9. Simplified Circuit Diagram

The basic voltmeter circuits are shown on simplified diagram figure 9. A complete schematic is at the end of the instruction book.

The basic parts of the voltmeter are:

3.1 Input and Midsection Attenuators

Two wide band attenuators are used in the Model 321 — the input attenuator at the input and the midsection attenuator between the amplifiers.

The voltmeter sensitivity change on all ranges is achieved by input and midsection attenuator except on 0.3 mV range where the gain of the amplifiers is increased.

3.1.1 Input Attenuator is connected to the voltmeter input over dc blocking capacitor. It consists of two separate attenuators R4, R6, and R4, R7, R8.

Below 20 kc the attenuator acts as a resistive divider; above 20 kc the attenuator is capacitive and attenuation ratio is adjustable with C6, C7 and C6, C8, respectively.

Stable, closely matched (0.1%) hermetically-sealed, deposited film resistors are used in attenuator. The attenuation ratios and the scale ranges on which the attenuator is in the circuit are shown in Table V.

TABLE V

ATTENUATION RATIOS

Voltage Range FULL SCALE	Input Attenuation Ratio	Midsection Attenuation Ratio	Total Attenuation Ratio	Total Gain of Amplifiers
.3 mV	1	1	1	84 db
1 mV	1	1	1	74 db
3 mV	1	3.162	3.162	74 db
10 mV	1	10	10	74 db
30 mV	31.62	1	31.62	74 db
100 mV	31.62	3.162	100	74 db
300 mV	31.62	10	316.2	74 db
1 V	1000	1	1000	74 db
3 V	1000	3.162	3162	74 db
10 V	1000	10	10000	74 db
30 V	31620	1	31620	74 db
100 V	31620	3.162	100000	74 db
300 V	31620	10	316200	74 db

3.1.2 Midsection Attenuator is a string type attenuator with resistors R40, R41 and R42. Because of the lower resistance values it acts as a resistive attenuator over most of the voltmeter frequency range. Slight

compensation at higher frequencies is achieved with C30 and C31.

The attenuation ratios with corresponding ranges are shown in Table V.

3.2 Input Amplifier is a stable, three-stage (tubes V1, V2 and V3) feedback amplifier with a gain of 135 and with approximately 42 db of overall feedback. On 0.3 mV range the gain of the amplifier is increased to 240 by shunting the feedback resistor R20. R29 serves to vary the gain slightly on this range.

The high frequency response of the amplifier is adjustable slightly with L1 on all ranges and with C20 on 0.3 mV range only.

3.3 Output Amplifier is also a stable, three-stage (V4, V5, ½ V7) feedback amplifier with a gain of 38 and with approximately 38 db of overall feedback. The last stage of the amplifier is a direct coupled cathode follower for low output impedance. By shunting part of the feedback resistor the amplifier gain is increased to 67 on 0.3 mV range. A slight high frequency adjustment on all ranges is possible with C36 and C44.

It drives one-half of the output transformer. The other half is driven by the phase inverter.

3.4 Phase Inverter is a two-stage (V6, ½ V7) phase reversing amplifier with the gain of 1 and with approximately 37 db of overall feedback. Together with output amplifier it drives the push-pull output transformer. The symmetry and balance of the drive is controlled by matched resistors R65 and R66 at low frequencies and with C46 at high frequencies.

3.5 Square Law Detector

The true rms response is achieved in the square law detector where the square law is synthesized by continuous sequence of linear segments. With this technique a wide band, instantaneous responding, wide dynamic range, overload-proof and accurate rms response is accomplished. The ideal characteristic of a square law detector is

$I_s = K \bullet E_s^2$

I_s — squarer current

E_s — voltage applied to the squarer

K — constant

The detector in the Model 321 approximates this law to $\pm 0.3\%$ for smoothly varying waveforms and to $\pm 0.5\%$ for flat top waveforms.

The squarer consists of 8 series-connected diodes CR4 - CR11. At every junction of diodes a pair of resistors (R82 - R91 for diode junction CR4 - CR5, etc.) supplies a dc bias and load to the junction. The bias voltage is increasing and the load resistance decreasing from diode CR4 to diode CR11. The signal, which is rectified in CR1, CR2 full wave rectifier passes through only the diodes whose bias is less than the instantaneous amplitude of the signal. At higher signal level more diodes are conducting, less load resistance is applied to the signal, and the squarer draws a current proportional to the square of the signal voltage. The rectified and squared current passes through a logarithmic indicator with 10 - 1 current range and 200 μA full scale sensitivity. Because of the square law of the detector, this current variation is produced by 3.16 - 1 input voltage range. The logarithmic scale of the indicator is retained with a voltage range of 10 db, even though the indicator has a current range of 20 db.

Capacitor C55, together with indicator movement inertia, averages the squared current. The diode CR3 is to protect the indicator from overload.

The sensitivity of the voltmeter is changed by changing the sensitivity of the square law detector by controlling the bias of all diode junctions with R71 SENS ADJ control. The temperature affects the forward characteristics of diodes, which are then compensated by the thermistor RT1.

In MEAN SQUARE output mode a 1000 ohm resistor R76, with averaging capacitor C56, is connected into the squarer circuit instead of the meter.

In NULL DET mode the squarer sensitivity is increased by disconnecting the bias on all diodes, and applying a small current in series with rectifiers and squaring network, which can be controlled by R77 NULL ADJ.

In AMP OUTPUT mode the squarer is disconnected and the transformer output connected to the output terminals for an ac output linearly proportional to the input voltage.

3.6 Average Circuit

In AVERAGE mode the function switch connects a low-pass filter L2 - C80 between the signal rectifiers and the square law network.

At the filter input there is a full wave rectified signal, but only the average dc component passes the filter. The average voltage is displayed by the indicator.

To compensate for the dc voltage drop in the filter choke, the gain of the second amplifier is increased by decreasing the feedback slightly with R130.

The calibration of the average indication is done by adjusting the load of the filter (R120).

3.7 Peak Circuit

In the PEAK mode a cathode follower V15 is connected between the signal rectifiers and the square law network.

Signal rectifier diodes (CR1 and CR2) with a 1.0 μF capacitor (C81) load act as the peak detector. Discharging occurs over the reverse leakage of the rectifier diodes.

The dc voltage corresponding to the higher repetitive peak voltage drives the indicator over the cathode follower and square law network. A single or random peak cannot be measured because the detector charging time constant is 150 μs.

The indication is proportional to the highest repetitive peak voltage, positive or negative, depending on the waveform. A linearity adjustment is provided for the lower part of the scale (R123). Sensitivity is adjusted by PEAK ADJ R127.

To compensate for the voltage drifts due to the heater voltage changes in the cathode follower tube 6DJ8, an adjustment is provided (R124).

3.8 Power Supply

Two dc power supplies are used, one with silicon rectifiers CR12 and CR13 to supply dc filament power to the tubes V1 and V2. A regulated high voltage supply with V10 as rectifier supplies the high voltage to amplifiers and squarer. The B+ supply to the amplifiers is stabilized by the V11 and V12 cold cathode regulator tubes, and to the output cathode-follower by V13 series regulator tube. A separate reference tube V14 stabilizes the bias voltage for squarer.

4. MAINTENANCE

4.1 General

The Model 321 is designed for extended trouble-free service. The use of high grade components operated below rating and low operating temperature results in more than 5,000 hours expected operating periods without the need for amplifier tube change.

The purpose of periodic maintenance procedures is to assure the specified accuracy, check the condition of the voltmeter and detect and replace deteriorated tubes or components before they have an appreciable effect on instrument performance. The procedure is designed not only to measure and correct voltmeter performance at the time of test, but to foresee the possible troubles and guarantee the instrument accuracy through the next maintenance period.

4.2 Recommended Maintenance consists of three types of periodic checks.

4.2.1 Meter screw adjustment after every 200 hours of operation.

4.2.2 1,000 hour check after every 1,000 hours of operation.

4.2.3 2,000 hour check after every 2,000 hours of operation.

4.3 Necessary Maintenance Equipment

4.3.1 DC Voltmeter, range 0 - 500 V, accuracy ±3%, input resistance 10 MΩ minimum.

4.3.2 Stable AC Voltage Source, 0.4 to 2 kc, 0.1 to 10 V output.

4.3.3 Calibrated AC Voltage Source, 0.4 to 2 kc, 0.1 to 1 V output, accuracy ±0.25% or better. Ballantine Model 421 AC-DC Precision Calibrator or Ballantine Model 350 0.25% accurate RMS Voltmeter with any stable voltage source is recommended.

4.3.4 Tube Tester to measure tube transconductance.

4.3.5 Calibrated, Variable RF Voltage Source, 1 kc to 5 Mc. Ballantine Model 440 Micropotentiometer with 0.2 Ω resistor and 5 mA thermocouple and a RF generator is recommended.

4.3.6 Variable Metered AC Power Supply 100 W

4.4 Removal of the Case

Place the voltmeter front down on a table. Remove the power cord and three #10 binder head screws at the rear of the case. Lift up the case. To replace the case proceed in reverse order.

WARNING: When instrument is operated without the case the danger of electric shock exists. Take extreme care not to come in contact with high voltage points. The highest voltage on chassis is 450 V dc.

4.5 Scale Adjustment

Scale adjustment checks the scale linearity of the logarithmic indicator. It is equivalent to the zero adjustment in linear meter. For scale adjustment:

Set	To
Function Switch	RMS METER
Range Selector	1 V

Apply a stable 100 cps to 10 kc signal to the input. Adjust the amplitude to give an indication exactly on 10 on upper voltage scale. Rotate range selector to 3 V range. If the indication is not at 1.0 on lower voltage scale, adjust the meter screw at the center of the meter face until indication is 1.0 ±0.2%. Repeat the procedure until full scale indication on 1 V range agrees exactly with down scale indication on 3 V range.

Do not use the meter screw to bring the pointer on marked scale when no signal is applied to the voltmeter.

4.5.1 PEAK Linearity Adjustment

Peak linearity adjustment R123 is provided to compensate for the long term drift caused by contact potential of the cathode follower tube V15 - 6DJ8.

This adjustment should be done after scale adjustment in RMS mode is checked (4.5).

For adjustment, first allow the instrument 1 hour warmup. Then

Set	To
Function Switch	PEAK METER
Range Selector	100 mV

Apply a 100 Hz to 10 kHz, low distortion (less than 0.25%) sine wave to the input and adjust the amplitude for an indication of exactly 10 on the upper voltage scale.

Rotate range selector to 300 mV range. If the indication is not at 1.0 on lower voltage scale, adjust PEAK LIN control R123 through the hole on the left side of the instrument for an indication of 1 ±0.2%. Repeat the procedure until full scale indication on 100 mV range agrees exactly with down scale indication on 300 mV range.

Do not use meter screw for this adjustment.

4.6 1,000 Hour Check

The 1,000 hour check tests the performance of the voltmeter as a whole to detect unexpected failure of any tube or component and to insure trouble-free operation for the next 1,000 hours.

4.6.1 Tests Comprising the 1,000 Hour Check

4.6.1.1 Bias test of V7 tube

4.6.1.2 Meter screw adjustment

4.6.1.3 Line voltage stability test

4.6.1.4 Midband accuracy test

4.6.2 Bias Test of V7 Tube

This test determines the condition of V7 tube. For the test remove the case, connect the power cord to the voltmeter, allow 5 minutes warmup. Short the voltmeter input and

Set	To
Range Selector	300 V
Function Switch	RMS METER

Set the power line voltage to 115 V ±1 V. Measure the potential between the cathodes (pins 3 and 8) and grids (pins 2 and 7) of each section of tube V7 - 8223 (6DJ8) located at the output amplifier printed board. Connect the ground lead of the DC voltmeter (4.3.1) to the cathode, high lead to the grid.

If either bias is below 1.5 V, replace tube. The tube replacement has negligible effect on voltmeter calibration. After test, replace the case.

4.6.3 Meter Screw Adjustment is made according to section 4.5.

4.6.4 Line Voltage Stability Test

This determines the condition of all tubes and detects any deterioration in tubes or components.

4.6.4.1 For the test, plug the voltmeter to a variable power supply (4.3.6). Set line voltage to 115 V ±1 V. Allow 20 minutes warmup. Connect a stable voltage source 0.4 - 2 kc (4.3.2) to the input of the voltmeter.

Set	To
Function Switch	RMS METER
Range Selector	300 mV or 10 V

Set the source voltage to produce indication exactly on some scale line.

4.6.4.2 Lower line voltage to 105 V ±1 V, wait 1 minute. Observe deviation from previous indication.

Limit of deviation 0.2% max

4.6.4.3 If the indication changes more than 0.2%, test the voltmeter according to 2,000 hour test described in section 4.7.

4.6.5 Midband Accuracy Test

4.6.5.1 Calibration Source — The calibration of the RMS, AVERAGE and PEAK modes can be checked most conveniently with an undistorted sine wave source of 100 cps to 10 kc (distortion less than 0.5%), or with a good square wave source of 1 kc to 10 kc.

The relationships between average to rms and peak to rms are as follows:

Waveform	Sine Wave	Square Wave
RMS	1	1
AVERAGE	0.9	1
PEAK	1.41	1

If there is available a precision sine wave source (Ballantine Model 421) with calibrated RMS and PEAK outputs, then only for the AVERAGE calibration is it necessary to rely on the RMS value and consider the form factor relationship.

Square waves should be used for calibration only if the flat portion has no droop or overshoot and if the half periods differ by no more than 0.5%.

In case no precision calibrator is available, a stable, undistorted sine wave source, together with a precision rms responding voltmeter (Ballantine Model 350) can be used as the calibrated source.

It is most convenient to check the calibration of all responses at the same time in the following order:

RMS, AVERAGE, PEAK.

4.6.5.2 Calibration Procedure — Power line voltage should be 115 V ±1 V. Let the instrument warm up a minimum of 30 minutes. Take off the instrument case.

Apply to the input terminals an undistorted sine wave signal 100 mV RMS ±0.1% (Ballantine Model 421 is recommended).

Set	To
Function Switch	RMS METER
Range Selector	100 mV

Indicator should read 100 mV.

If indication differs by more than ±0.3%, adjust RMS SENS ADJ R71 control for 100 mV ±0.1%. This control is located at the rear of the instrument.

Set	To
Function Switch	AVER METER

Indicator should read 90 mV.

If indication differs by more than ±0.3%, adjust AVER ADJ R120 control on the left side of the instrument for a reading of 90 mV ±0.1%.

PEAK COMP control R124 setting should be checked before PEAK calibration.

Set	To
Power Line Voltage	115 V ±1 V
Function Switch	PEAK METER
Range Selector	Any range

Apply sine wave signal 100 cps to 10 kc to input.

Adjust reading exactly to some division on left end of scale. Vary the power line voltage to 125 V. If pointer settles, after a transient, to a different reading with a drift of more than ±0.5%, then, using PEAK COMP control R124 on the left side of the instrument, bring the pointer back to first setting.

Change line voltage back to 115 V. Observe the pointer and make necessary readjustments until the variation is brought into limits of ±0.5%. After PEAK COMP is readjusted, the PEAK

calibration R127 can be checked and, if necessary, readjusted.

Set	To
Function Switch	PEAK METER

If calibration source has PEAK or PEAK-TO-PEAK calibrated signal available, apply 100 mV Peak or 200 mV Peak-To-Peak (Ballantine Model 421 has RMS and Peak-To-Peak available, with accuracy ±0.1%).

Indicator should read 100 mV.

If indication differs by more than ±0.5%, adjust PEAK ADJ control R127 on left side of the instrument for a reading of 100 mV ±0.2%.

Set Range Selector to the next higher (300 mV) range.

If indication differs by more than ±0.5%, adjust PEAK LIN control R123 on left side of the instrument for a reading of 100 mV ±0.2%.

If PEAK LIN is considerably off, set Range Selector back to 100 mV range, readjust PEAK ADJ control, and repeat PEAK LIN adjustment until the readings are within proper limits on both ranges. Repeated adjustment is necessary because adjustments are interdependent.

In case the PEAK or PEAK-TO-PEAK calibrated signal is not directly available, and relying on RMS value:

100 mV RMS	gives	141.4 mV Peak
70.7 mV RMS	"	100.0 mV Peak

4.7 2,000 Hour Check

The 2,000 hour check, besides testing the voltmeter as a whole, tests the tubes and some critical subassemblies. It also tests the frequency response of the voltmeter.

4.7.1 Tests Comprising the 2,000 Hour Check

4.7.1.1 Power supply test
4.7.1.2 Bias test on V7
4.7.1.3 Tube test
4.7.1.4 Meter screw adjustment
4.7.1.5 Line voltage stability test
4.7.1.6 Frequency response test
4.7.1.7 Midband accuracy test

4.7.2 Power Supply Test

Remove the case, connect power cord to 115 V ±1 V supply. After 5 minute warmup:

Set	To
Function Switch	RMS METER
Range Selector	300 V

Short the voltmeter input.
Measure dc voltage on pin 8 of rectifier tube V10 - 5V4G.
If the voltage is below 390 V replace V10.
Measure the bias of tube V13 - 12B4A between pins 1 and 7 or between terminals F and H.
Replace tube V13 if bias is below 5 V.

4.7.2.1 Lower the line voltage to 105 V ±1 V, turn the voltmeter off and after 1 minute, on again. Observe V11 — OA2 and V12 — OB2 — both tubes should strike. Replace the tube which does not strike.

4.7.3 Bias Test on V7 is made according to the section 4.6.2.

4.7.4 Tube Test

Identify the tubes and sockets so that the tubes could be returned to the same sockets. Remove the tubes, check the tubes in a tube tester. Replace the tubes with transconductance less than the lowest limit specified by the tube manufacturer. Return the acceptable tubes to the original sockets.

4.7.4.1 Change of V7 - 8223 (6DJ8), V10 - 5V4G, V11 - OA2, V12 - OB2, V13 - 12B4A - has negligible effect on voltmeter performance and no readjustment or recalibration is needed after the tube change.

Replacement of V14 - 5651 may affect the sensitivity only.

Change of V1 - 5654 may affect the noise and high frequency response above 2 Mc slightly. Check of high frequency response is recommended when the utmost accuracy at higher frequencies is desired. Also check hum after replacement of V1 and V4 according to section 5.11.

Change of V5 - 6EJ7 may affect the voltmeter response above 1 Mc, and a frequency response check according to section 5.7 is needed.

4.7.5 Frequency Response Test

Connect the calibrated hf voltage source to the voltmeter. When Ballantine Model 440 Micropotentiometer is used, use setup shown in figure 10.

Set	To
Function Switch	RMS METER
Range Selector	1 mV

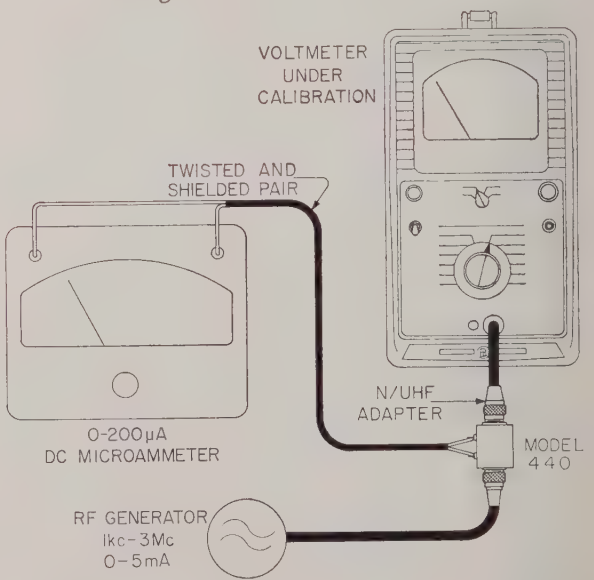


Fig. 10. Connection of Micropotentiometer

Set hf generator to 1 kc, adjust output to produce an indication exactly on a scale point at midscale (5, 6 or 7). Note the rf input level or indication on DC Microammeter when Model 440 is used.

4.7.5.1 Keep the input voltage to voltmeter constant (constant indication on Model 440 Microammeter). Change the frequency to 0.5, 1, 2, and 4 Mc. Observe the indication on Model 321. In should differ from 1 kc indication not more than the following amounts:

±1%	at	0.5 Mc
±1%	at	1 Mc
+2, −0%	at	2 Mc
±3%	at	4 Mc

Recalibrate the voltmeter according to section 5.7 if the deviation exceeds the limits stated above.

4.7.6 Midband Accuracy Test
Make the test as described under section 4.6.5.

5. SERVICE AND TROUBLESHOOTING

5.1 General

In case of voltmeter malfunction, servicing by the user is feasible, provided skilled personnel and recommended equipment are available and the procedures outlined below are followed. However, it should be pointed out that described procedures are only simplified outline of service and calibration. Refined service and comprehensive calibration requires accurate and special equipment which may not be available to the user. Therefore, if this is the case, or if trouble develops which cannot be corrected by the simplified methods outlined here, or when most accurate calibration of the voltmeter is needed, it is recommended that the voltmeter be returned to Ballantine Laboratories for service and recalibration. The instrument should in all cases be preceded by a letter giving the exact nature and symptoms of the trouble. (See Section 6 for shipping instructions.)

5.2 Necessary Equipment

For successful servicing and troubleshooting the following equipment is needed:

5.2.1 DC Voltmeter, Ohmmeter, 0 - 500 V, ±3% accuracy, 10 MΩ or higher input resistance. RCA Voltohmist or equivalent.

5.2.2 Sensitive DC Voltmeter, 0.02 to 2 V, 1% accuracy, 1 MΩ or higher input resistance. Ballantine Model 365 is recommended.

5.2.3 Sensitive AC Voltmeter, 1 mV to 100 V, frequency range 10 cps to 100 kc, ±3% accuracy. 1 MΩ or higher input impedance. Ballantine Model 300H, 302C or similar voltmeter is recommended.

5.2.4 Signal Generator, 5 cps to 5 Mc, 0.1 mV to 30 V output.

5.2.5 Accurate RF Voltage Calibrator, output 1 mV, 10 mV, 30 mV, 1 V and 30 V, flatness of the frequency response ±0.25% from 1 kc to 4 Mc. Ballantine Model 440 Micropotentiometer with 5 mA thermocouple and 0.22 Ω, 2.2 Ω and 6.8 Ω resistors is recommended for 1 mV, 10 mV and 30 mV standard.

Ballantine Model 393 HF Transfer Voltmeter with Model 1393-50 50 V probe is recommended for 30 V standard, 1393-2 2 V probe for 1 V standard.

5.2.6 Accurate Calibrated 1 kc Voltage Source, frequency 1 kc, voltage accuracy 0.25% output 1 mV to 10 V. Ballantine Model 420 or Model 421 AC-DC Precision Calibrator is recommended.

5.2.7 HF Diode Voltmeter, 0 - 3 V, input capacity 10 pF, or lower. Ballantine Model 340 or Model 345 is recommended.

5.3 Simple Service Problems

5.3.1 Removal of the Case is required for service tests.

Place the voltmeter front down on a table. Remove the power cord and three #10 binder head screws at the rear of the case. Lift up the case. To replace the case proceed in reverse order.

WARNING: When instrument is operated without the case the danger of electric shock exists. Take extreme care not to come in contact with high voltage points.

The highest voltage on chassis is 450 V dc.

5.3.2 Pilot Light Replacement

Unscrew the red plastic cap. Remove the burned out pilot light from its bayonet base. Replace with Type 47, or Type 1815 bulb for longer life.

5.3.3 Fuse Replacement

For fuse replacement unscrew the fuse holder cap, pull out the fuse.

For replacement use

0.8 A Slo-Blo ¼" x 1¼" fuse for 115 V operation
0.4 A Slo-Blo ¼" x 1¼" fuse for 230 V operation

Investigate and correct the cause for fuse failure before replacing the fuse.

5.3.4 Tube Replacement is needed when the tubes in voltmeter show low transconductance, have developed grid current, heater cathode leakage or any other defect. All tubes which meet the tube manufacturer's specifications may be used — no special selection is needed. Some replacements require checks of the high frequency response as described under 4.7.4.1 or noise

and hum check described under section 5.11. Do not replace tubes which check normal.

5.4 A DC Voltage Check is needed when voltmeter shows malfunction which cannot be corrected by tube replacement.

5.4.1 For the check, remove the case, remove the shield on the input amplifier board, connect the voltmeter to 115 V ±1 V power, short the input terminal and

Set	To
Function Switch	RMS METER
Range Selector	300 V

5.4.2 Measure the dc voltage at pin 8 of rectifier tube V10 - 5V4G.

Replace the tube if the voltage is below 390 V.

Measure the bias of the tube V13 - 12B4A between pins 1 and 7 or terminals F and H power supply printed board connector.

Replace the tube 12B4A if voltage difference between pin 1 and 7 is below 5 V.

5.4.3 Measure the pin voltages of all tubes with DC Voltmeter. Compare the result with the values given on schematic. They should agree to 15%. If any voltage is outside the 15% limit, check the associated tube and components until the reason for deviation is found.

5.4.4 Check the grid current and biases of the tubes by measuring the grid voltages. The limits are shown in Table VI.

TABLE VI

GRID VOLTAGE LIMITS			
Tube	**Type**	**Pin**	**Voltage**
V1	5654	1	0.01 V max
V2	6EJ7	2	0.3 V max
V3	6EJ7	2	0.3 V max
V4	5654	1	0.1 V max*
V5	6EJ7	2	4.2 V min
V6	6EJ7	2	4.2 V min
V7	8223	7	1.5 V min**
	(6DJ8)	2	1.5 V min**

* measured between pin 1 and terminal 21 of the output amplifier board

** measured between cathode and grid (pin 8 - 7 and 2 - 3)

Replace the tubes with excessive grid current.

5.4.5 See Section 4.7.4.1 for necessary adjustments after tube change. For dc voltages in square detector circuit see section 5.6.3.

5.5 Signal Tracing is recommended when the voltmeter malfunction cause cannot be found by dc voltage measurement.

For signal tracing, remove the case, connect the voltmeter to 115 V power, apply 1 mV ±1% 1 kc signal to the input,

Set	To
Function Switch	RMS METER
Range Selector	1 mV

Use the sensitive AC VTVM to measure the pin voltages. They should agree within ±5% with the values marked in the schematic.

When measuring ac voltages check all voltages within the amplifier because in the feedback amplifier trouble in one stage may affect the ac voltages elsewhere in the circuit. Therefore location of an incorrect ac level does not necessarily pinpoint a trouble location.

If the signal voltage measures normal at the squarer input but incorrect indication is observed, check the square law detector and indicator circuit.

5.6 Check of Square Law Detector and Indicator is needed when the signal in amplifier circuit is normal but 5 V signal at the input of the rectified diodes CR1, CR2 (terminals 40 and 41) does not produce a full scale indication. The defect may be located by the following tests.

5.6.1 Continuity Test

For the test turn the voltmeter off.

Set	To
Function Switch	RMS METER
Range Selector	Any position

Measure dc resistance from input of CR1 or CR2 (terminal 40 or 41) to ground. The resistance should be approximately 600 Ω and a positive potential from terminal 40 or 41 to ground should cause the Model 321 indicator to deflect.

5.6.2 Diode Test

Measure the forward and reverse resistance of each diode in squarer circuit (CR1 to CR11) separately, using Voltohmist or similar instrument. The forward resistance is approximately a few hundred ohms. The reverse resistance 10 kΩ to 30 kΩ.

Replace the diodes which show shorts or are open. Use the types listed on parts lists. Use diodes which at room temperature have less than 0.5 μA reverse current when 0.5 V reverse voltage is applied.

5.6.3 Squarer Bias Test

For the test, turn the voltmeter on,

Set	To
Function Switch	RMS
Range Selector	300 V

Short the input terminals.

Measure dc voltages from diode junctions to chassis and compare with Table VII.

Replace the diode CR4 if the voltage at diodes CR1, CR2, CR4 is above 0.03 V. Use diodes listed in parts list. Check the reverse leakage which should be below 0.3 μA at 0.5 V reverse voltage and at 25°C.

If the junction voltage is outside the limits, check the diodes to higher voltage junction for leakage. Replace leaky diodes.

TABLE VII

SQUARER BIAS LIMITS				
Diode Junction	**Voltage at Diode Junction*** Voltage on Terminal 43			**Limit**
	65	70	75	
CR1, CR2, CR4	0.02	0.02	0.02	.03 max
CR4, CR5	0.50	0.54	0.58	±3%
CR5, CR6	0.84	0.90	0.97	±3%
CR6, CR7	1.25	1.35	1.45	±3%
CR7, CR8	1.87	2.0	2.15	±3%
CR8, CR9	2.8	3.0	3.2	±5%
CR9, CR10	4.2	4.5	4.8	±5%
CR10, CR11	6.3	6.8	7.3	±5%
R89, R98	10.4	11.1	11.8	

*Interpolate the voltage values if the terminal voltage is not exactly 65, 70 or 75 V.

5.6.4 Electrical Linearity (R90) needs adjustment when the voltmeter has normal full scale sensitivity but the meter screw has inadequate range for bottom scale adjustment. The electrical linearity control R90 is located at the squarer board and may be adjusted through the hole marked LIN ADJ at the rear of the case.

5.6.4.1 For the adjustment turn the instrument on, allow 20 minutes warmup, then

Set	To
Function Switch	MEAN SQUARE
Range Selector	1 V

Apply a 1 V signal to the input. Connect a sensitive dc voltmeter to the MEAN SQUARE output connector on the front panel of the Model 321. It should indicate approximately −0.2 V. Readjust the input signal until the output is −0.2 V ±0.5%.

5.6.4.2 Turn Range Selector to next higher (3 V) range. Adjust the R90 LIN ADJ until the output is −0.0206 V ±0.5%. Repeat the steps 5.6.4.1 and 5.6.4.2 until the output is in specified limits at either range selector setting.

5.7 Frequency Response Alignment

Typical frequency response of the voltmeter with 1 kc response as reference is shown on figure 11.

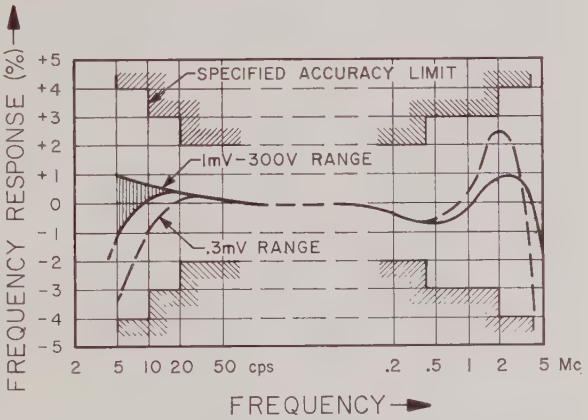


Fig. 11. Typical Frequency Response

If the frequency response at any range differs more than ±1 to 2% from the typical response shown in the graph, the response alignment is needed.

5.7.1 Low Frequency Response has no alignment controls. Its deviation from the normal response is

TABLE VIII

RESPONSE ALIGNMENT CONTROLS				
Order of Alignment	**Assembly**	**Adjustment**	**Affects Ranges**	**Adjust on Range**
1	Amplifier	C44	all ranges	1 mV
2	Midsection Attenuator	C30	3, 100 mV; 3, 100 V	3 mV
3	Midsection Attenuator	C31	10, 300 mV; 10, 300 V	10 mV
4	Input Attenuator	C6	30 mV and up	1 V
5	Input Attenuator	C7	30, 100, 300 mV	30 mV
6	Input Attenuator	C8	30, 100, 300 V	30 V
7	Amplifier	C20	0.3 mV	0.3 mV

In case of an error on several ranges, this table helps to determine the control which has to be adjusted. A more detailed alignment procedure is outlined in Table IX at the rear of this instruction book.

caused by the changes of amplifier coupling or decoupling networks or deterioration of amplifier tubes. The most probable cause is the development of grid current in some stage. Normal response will be restored after the replacement of defective component or tube.

5.7.2 High Frequency Response may deviate from normal response because of the change in amplifier response or changes in attenuator compensation. Amplifier response adjustment affects the responses of all ranges.

The attenuator adjustment offsets only certain ranges as indicated in Table VIII.

5.7.3 Amplifier Response Alignment is needed when the response of all ranges deviates from normal response.

Two controls are available for alignment. The Control C44 aligns the ranges from 1 mV to 300 V and a separate control C20 aligns the 0.3 mV range. C44 adjustment affects also 0.3 mV range and should be done before this range is adjusted.

5.7.3.1 For amplifier response adjustment remove the case, allow 5 minutes warmup and connect stable 1 kc to 5 Mc signal source 0.5 - 1 mV output to the input (Ballantine Model 440 with 5 mA thermocouple and 0.22 Ω resistor) as shown on figure 10.

Two steps are necessary for amplifier response alignment.

5.7.3.2 Phase Inverter Balance Check. This is needed when resistor R65, R66, R67 or tube V6 has deteriorated.

Set	To
Function Switch	AMPLIFIER
Range Selector	1 mV

Apply a 0.5 to 1 mV 1 kc signal to the input. Measure the voltage from CT to IN PHASE and REVERSE output terminal using diode voltmeter (5.2.7). The voltage at both output terminals should be equal within ±0.2%. If the voltage differs more, check R65, R66, and R67. R65 and R66 are matched pair to 0.1%.

5.7.3.3 Change the input frequency to 3 Mc. Measure the voltage at the same output terminals. If the voltage differs more than 0.2% adjust the voltage on IN PHASE terminals with C46 HF BAL control which is located at the tube side of output amplifier printed board until the voltage agrees with voltage at REVERSE terminal.

5.7.3.4 Amplifier Response Alignment. For the adjustment remove the case and

Set	To
Function Switch	RMS METER
Range Selector	1 mV

Apply a 1 kc 0.5 - 1 mV signal to the voltmeter through Model 440 Micropotentiometer (5 mA thermocouple with 0.22 Ω resistor). Adjust the signal to produce an indication directly to some scale line on the indicator. Note micropotentiometer dc output.

5.7.3.5 Change the signal frequency to 3 Mc. Adjust the RF amplitude exactly to the 1 kc amplitude applied to the voltmeter before by adjusting the level to the same dc output from micropotentiometer.

The indication on voltmeter should be ±0.5 to +1.5% above the previous indication. If not, adjust C44 on the output amplifier board until the indication is ±0.5 to +1% above the 1 kc indication.

5.7.4 0.3 mV Range Adjustment is needed when the response of 1 mV range is normal but 0.3 mV differs from the normal response. For the adjustment remove the case and

Set	To
Function Switch	RMS METER
Range Selector	.3 mV

Apply a 0.3 mV 1 kc signal to the voltmeter input through Model 440 Micropotentiometer (5 mA thermocouple with 0.22 Ω resistor). Adjust signal to produce indication exactly on some scale line; note the micropotentiometer dc output.

5.7.4.1 Change signal frequency to 3 Mc. Adjust rf amplitude exactly to 1 kc amplitude by adjusting the level to give the same dc output from the micropotentiometer. Adjust C20 through the left hole (see figure 13) on the shield at input amplifier board until the 3 Mc indication is within +2 to +3% of 1 kc indication.

5.7.5 C30 Midsection Attenuator Adjustment is needed when the voltmeter response on 1 mV range is normal but deviates from normal on 3, 100 mV and 3, 100 V range. For the adjustment, remove the case and

Set	To
Function Switch	RMS METER
Range Selector	3 mV

Apply a stable 2 - 3 mV 1 kc signal to the input. Use Model 440 Micropotentiometer (5 mA thermocouple with 2.2 Ω resistor). Adjust signal to produce an indication at some scale line between 2 and 3. Note the input level.

5.7.5.1 Change signal frequency to 3 Mc. Adjust the amplitude exactly to 1 kc amplitude by adjusting level to give same dc output from the Micropotentiometer. Adjust C30 until voltmeter indicates +1 to 2% above the 1 kc indication. C30 is the top trimmer on Range Selector rear deck as shown in figure 14.

5.7.6 C31 Midsection Attenuator Adjustment is

needed when voltmeter response is normal on 1 mV range but deviates from normal to 10, 300 mV and 10, 300 V ranges. For the adjustment, remove the case.

Set	To
Function Switch	RMS METER
Range Selector	10 mV

Apply a stable 1 kc 5 mV - 10 mV signal to the voltmeter, through Model 440 Micropotentiometer (5 mA thermocouple with 2.2 Ω resistor). Adjust the signal for an indication on some scale line. Note the micropotentiometer dc output.

5.7.6.1 Change the signal frequency to 3 Mc. Adjust the amplitude exactly to 1 kc amplitude by adjusting level to give same dc output from the Micropotentiometer. Adjust C31 until voltmeter indicates 0 to 1% above 1 kc indication. The C31 is the lower trimmer on Range Selector near deck as shown in figure 14.

5.7.7 Input Attenuator Adjustments are made with the voltmeter in case. The trimmers are accessible through the front panel openings after removal of the escutcheon plate. For removal of escutcheon plate remove the function switch and range selector knob. Remove four #4 nickel plated binder head screws at the corners of the escutcheon plate and lift off the escutcheon plate. The adjustment holes under the escutcheon plate are marked on the panel.

Adjust the input attenuator in sequence shown on Table VIII or IX.

5.7.7.1 C6 Input Attenuator Adjustment is needed when voltmeter response on 1 mV range is normal but differs from normal on ranges from 30 mV and up.

For the adjustment:

Set	To
Function Switch	RMS METER
Range Selector	1 V

Apply a stable 1 V 1 kc signal to the voltmeter. Monitor the signal with Model 393 Transfer Voltmeter (with 1393-2 probe) as shown in figure 11. Adjust the signal to produce indication exactly on some scale line. Register the level by balancing AC BALANCE on Model 393.

5.7.7.1.1 Change signal frequency to 50 kc. Adjust the level exactly to 1 kc level using Model 393 Transfer Voltmeter. Adjust C6 using insulated screwdriver until voltmeter indication agrees with 1 kc indication to ±0.2%.

5.7.7.2 C7 Input Attenuator Adjustment is needed when voltmeter response on 1 mV range is normal but differs from normal on 30 mV, 100 mV and 300 mV range.

For the adjustment:

Set	To
Function Switch	RMS METER
Range Selector	30 mV

Apply a stable 1 kc 20 - 30 mV signal to the voltmeter through Model 440 Micropotentiometer (5 mA thermocouple 6.8 Ω resistor). Adjust the signal to produce indication exactly on some scale mark. Note the dc output from Model 440.

5.7.7.2.1 Change signal frequency to 50 kc. Adjust signal amplitude exactly to 1 kc amplitude by adjusting the level to give same dc output from the Micropotentiometer. Adjust C7 until voltmeter indicator agrees with 1 kc indication to ±0.2%.

5.7.7.3 C8 Input Attenuator Adjustment is needed when voltmeter response on 1 mV range is normal but differs from normal on 30 V, 100 V and 300 V range.

For the adjustment:

Set	To
Function Switch	RMS METER
Range Selector	30 mV

Apply a stable 30 V 1 kc signal to the input voltmeter. Monitor the signal with Model 393 Transfer Voltmeter (with 393-50 probe) as shown on figure 12. Adjust the signal to produce indication exactly on some scale line. Register the level by balancing AC BALANCE on Model 393.

5.7.7.3.1 Change signal frequency to 3 Mc. Adjust the level exactly to 1 kc level using Model 393 Transfer Voltmeter. Adjust C8 until voltmeter indication is +0.5 to 1.0% higher than 1 kc indication.

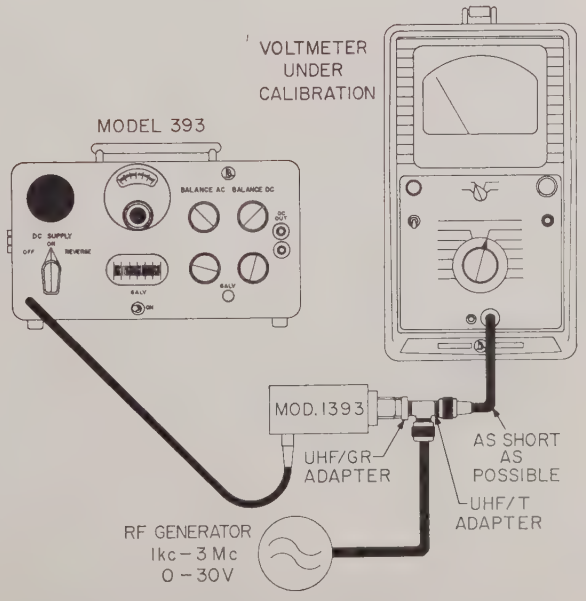


Fig. 12. Connection of HF Transfer Voltmeter

5.8 Sensitivity Adjustment

Sensitivity adjustment should be made according to section 4.6.5.

5.8.1 R29 .3 mV Range Sensitivity Adjustment is needed when only .3 mV range is in error at mid-frequencies.

For the adjustment, remove the instrument from the case, allow 15 minutes warmup, and

Set	To
Function Switch	RMS METER
Range Selector	.3 mV

Apply a stable 1 kc signal 0.3 mV ±0.25% to the voltmeter and adjust R29 until voltmeter indicates 0.3 mV ±0.2%. R29 is located at the input amplifier board and is adjustable through the hole in the shield as shown in figure 13.

5.9 Table of Calibration Controls, their locations, ranges they affect and frequencies and limits of adjustments are shown at the end of the instruction book, Table IX.

5.10 Service of Attenuators

Stable, carefully matched resistors are used in the attenuator. They do not dissipate any appreciable power and therefore their failure is very unlikely. Before replacing any resistors investigate possible trouble sources such as grid current in tube V1 or V4, bad switch contact, etc.

For the replacement, check voltmeter error at midfrequency on ranges 3, 10, 30 mV and 1, 10 and 30 V. Tabulate the error. The error spread — maximum positive error less maximum negative error — should not exceed 0.3% because the attenuator resistors are matched to 0.1%.

If one of the ranges shows more error than allowed within the 0.3% spread, one or more of the midsection or input attenuator resistors must be defective. The defective string may be determined from the schematic or from the Troubleshooting Chart (Section 5.13).

5.10.1 To replace an attenuator resistor measure the dc resistance of all resistors in the attenuator string with 0.05% or better accuracy. The resistance value may vary ±1% from the nominal value indicated on schematic but all resistors should be matched to ±0.1%. Replace the resistor which differs more than 0.1% from correct matching. Use resistors of same type and make for replacement because different makes may have different high frequency characteristics.

5.10.2 After replacing the resistor, check error in all ranges and make sure that error spread does not exceed 0.3%. Adjust voltmeter sensitivity (R71 adjustment, section 4.6.5) so that maximum positive error equals approximately the maximum negative error. This condition gives the least measuring error.

5.10.3 Because of the close matching of the resistors a single replacement may not be obtained from Ballantine Laboratories and in most cases a whole string has to be replaced. For that reason it is recommended that the voltmeter be sent to Ballantine Laboratories for attenuator service.

5.11 Intrinsic Noise and Hum Test should be done after tube replacement (see section 4.7.4.1) or when instrument performs erratically on lower ranges, reads high on most sensitive range, or has high error when line frequency voltage is measured.

5.11.1 For noise check short the INPUT terminals of Model 321.

Set	To
Function Switch	AMPLIFIER
Range Selector	.3 mV

Connect a wide-band voltmeter (4 Mc or more) to AMPLIFIER output terminals at the rear of Model 321 (high terminal to IN PHASE or REVERSE and low terminal to CT).

Measure noise voltage. Limit: 400 mV RMS maximum on .3 mV range and 125 mV RMS maximum on 1 mV range.

If noise is erratic or considerably higher, try new tubes starting in the order V1, V2, V4. VR tubes V11 and V12 may also be a source of erratic fluctuating noise. The other possible noise sources are described in Troubleshooting Chart.

5.11.2 For hum check connect an oscilloscope to AMPLIFIER terminals of Model 321.

Set	To
Function Switch	AMPLIFIER
Range Selector	.3 mV

Short INPUT terminals of Model 321. Normal noise consists of wide-band noise with harmonics of power frequency relatively much lower or hardly noticeable. If high hum is present look for possible sources in Troubleshooting Chart.

5.12 Service of the Power Supply

The power supply dc voltages and typical ripple voltages are shown in the schematic at the end of the instruction book. In case of trouble, the dc and ripple voltage check will discover the most common faults.

The condition of VR tubes (V11, V12, V14) can be checked by lowering the line voltage to 100 V and checking the starting of the tubes at low line voltage. Sometimes excessive amplifier noise may be caused by the VR tubes whose level may fluctuate slightly. Those tubes should be replaced. The series regulator tube V13 for the output stage should have a bias of 5 V minimum between pin 1 and 2.7 with 115 V line voltage. Replace the tube with smaller bias.

5.13 Troubleshooting Chart

In the following chart the effects of possible malfunction of a component or maladjustments of controls are described:

Symptoms	Possible Cause	Pertinent Sections
Instrument inoperative Pilot light does not light up	No power; blown fuse; Defective power supply	5.3.3 5.12
Meter indicating with shorted input	Voltmeter in NULL DET mode; Defective tubes; defective coupling or decoupling capacitor or range selector switch, etc.	2.14 2.5.2
Meter indicating with no signal	Input not properly shielded; Voltmeter in NULL DET mode	2.5 2.14
Sensitive to mechanical shock	Microphonic tubes V1, V2, V4, etc.; Loose connection	5.11 5.5
High error at 60 cps measurement	Hum pickup through input wiring; High ground current; defective tubes V3, V4	2.5 5.11.2
High error at 120 cps measurement	Heater cathode short of V1, V2; High ripple of +B supply; open filter capacitors; inoperative VR tubes V11, V12; High dc heater ripple; Open bypass or decoupling capacitor	5.11 5.12
High error on lower part of the scale (RMS, AVER, PEAK)	Meter screw out of adjustment; Squarer control R90 out of adjustment; Leaky capacitors C47, C48 or output transformer; Leaky function switch wafer	4.5 5.6.4
Instrument is out of calibration: a. on all ranges at low frequencies	Voltmeter in NULL DET mode; R71 SENS ADJ off; Defective tube or component; Meter screw off; defective diode in squaring network	2.14 4.6.5 4.5 5.6.2, 5.6.3
b. on all ranges at frequencies above 1 Mc	Amplifier frequency response off; Deteriorated tube; defective component	5.7.3
c. on every third range at low frequencies	Defective resistor in midsection attenuator	5.10
d. on every third range at frequencies above 1 Mc	C30 or C31 misadjusted	5.7.5, 5.7.6
e. on three sequential ranges at low frequencies	Defective resistor in input attenuator	5.10
f. on three sequential ranges at high frequencies above 30 kc	C6, C7 or C8 misadjusted	5.7.7

Troubleshooting Chart (Continued)

Sequential ranges don't agree (RMS, AVER, PEAK)	Weter screw or R90 LIN ADJ misadjusted; Diode CR3 leaky	4.5 5.6.4 5.6.3
Excessive flutter of pointer below 10 cps	Open C55	3.5
Pointer sluggish and positive errors at the bottom scale	Defective C55	3.5
High scale linearity error (RMS, AVER, PEAK)	Defective squarer diode or resistor	5.6
High scale linearity error on PEAK	PEAK LIN control needs adjustment	5.6.4.3
Power line voltage variation affects peak reading more than $\pm 1\%$	PEAK comb control needs readjustment	5.6.4.3

6. SHIPPING INSTRUCTIONS

If it should be necessary to return the instrument to Ballantine Laboratories, Inc. make certain that at least four inches of padding material surrounds the instrument to prevent damage during shipment. Ship via REA Express, motor truck, or air freight, to

Ballantine Laboratories, Inc.
90 Fanny Road
Boonton, New Jersey

TABLE IX

CALIBRATION TABL

Order of Adjustment	CONTROL					
	Designation	Location	Controls	Affects Ranges	Adjust On Range	
1	R65, 66, 67	Output Amplifier Board TB3	L.F. Balance of Phase Inverter	All	1 mV	M
2	C46	Output Amplifier Board TB3	H.F. Balance of Phase Inverter	All	1 mV	M
3	C44	Output Amplifier Board TB3	Amplifier H.F. Response	All	1 mV	M
4	C20	Input Amplifier Board TB2	.3 mV Range H.F. Response	.3 mV	.3 mV	M
5	C30	Range Selector Rear Deck	Midsection Attenuator H.F. Response	3, 100 mV 3, 100 V	3 mV	M
6	C31	Range Selector Rear Deck	Midsection Attenuator H.F. Response	10, 300 mV 10, 300 V	10 mV	M
7	C6	Behind Escutcheon Plate	Input Attenuator H.F. Response	30 mV - 300 V	1 V	M
8	C7	Behind Escutcheon Plate	Input Attenuator H.F. Response	30, 100, 300 mV	30 mV	M
9	C8	Behind Escutcheon Plate	Input Attenuator H.F. Response	30, 100, 300 V	30 V	M
10	R71	Rear, Through Hole	Voltmeter Sensitivity	All	1 mV - 300 V	M
11	R29	Input Amplifier Board TB2	.3 mV Range Sensitivity	0.3 mV	0.3 mV	

E

CALIBRATION SIGNAL			Adjustment Limits %	Remarks
Recommended Source	Frequency	Accuracy		
lodel 420 Calibrator	1 kc	Not Important	±0.2%	Adjust for Equal Output from In Phase and Reverse Terminals to Chassis
lodel 440, 5 mA TC, 0.22 Ω Res	3 Mc	Not Important	±0.2%	
lodel 440, 5 mA TC, 0.22 Ω Res	3 Mc	±0.2% Reference 1 kc	+0.5 to 1.5%	Adjust in Reference of 1 kc
lodel 440, 5 mA TC, 0.22 Ω Res	3 Mc	±0.2% Reference 1 kc	+1 to 3%	Adjust in Reference of 1 kc
lodel 440, 5 mA TC, 2.2 Ω Res	3 Mc	±0.2% Reference 1 kc	+0.5 to 1%	Adjust in Reference of 1 kc
lodel 440, 5 mA TC, 2.2 Ω Res	3 Mc	±0.2% Reference 1 kc	+0.5 to 1%	Adjust in Reference of 1 kc
lodel 393 with 1393-2 Probe	50 kc	±0.2% Reference 1 kc	±0.1%	Adjust in Reference of 1 kc
lodel 440, 5 mA TC, 6.8 Ω Res	50 kc	±0.2% Reference 1 kc	±0.1%	Adjust in Reference of 1 kc
.odel 393 with 1393-50 Probe	3 Mc	±0.2% Reference 1 kc	0 to 1.5%	Adjust in Reference of 1 kc
:odel 420 Calibrator	1 kc	±0.2%	±0.1%	After Complete Warmup
	1 kc	±0.2%	±0.2%	After Complete Warmup

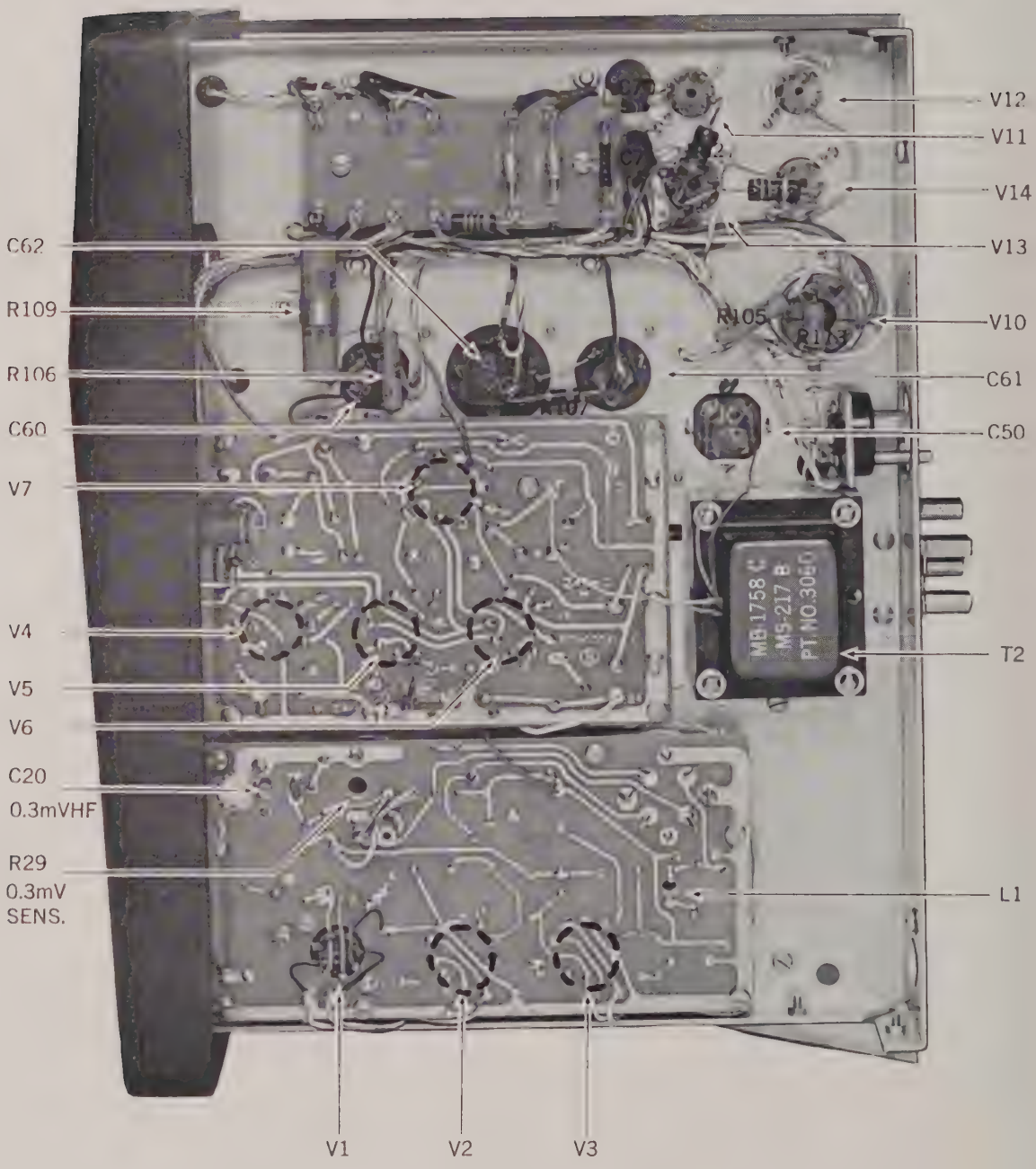


Fig. 13. Side View of Model 321 (right)
Showing Location of Tubes and Adjustments

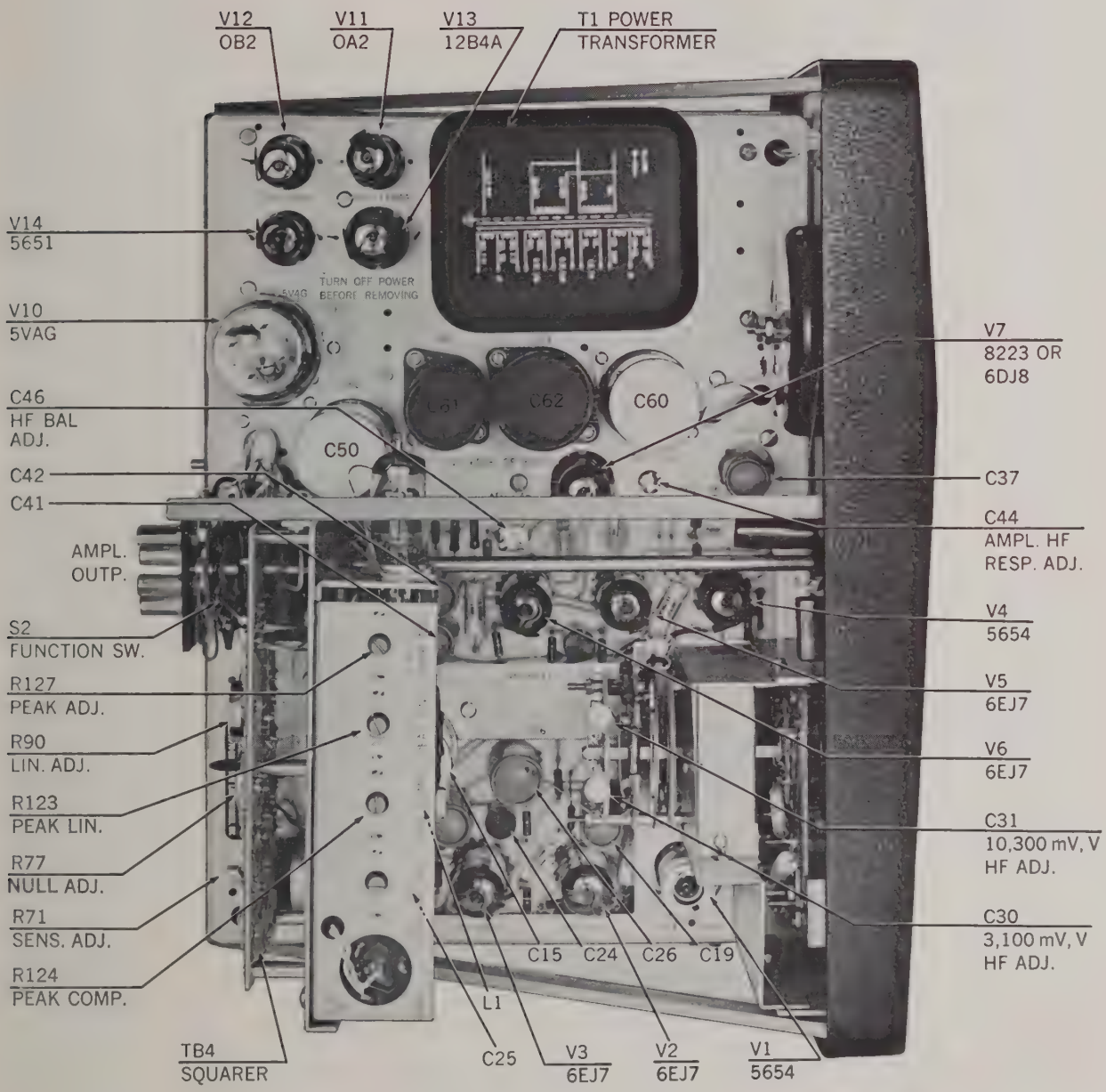


Fig. 14. Side View of Model 321 (left)
Showing Location of Tubes and Adjustments

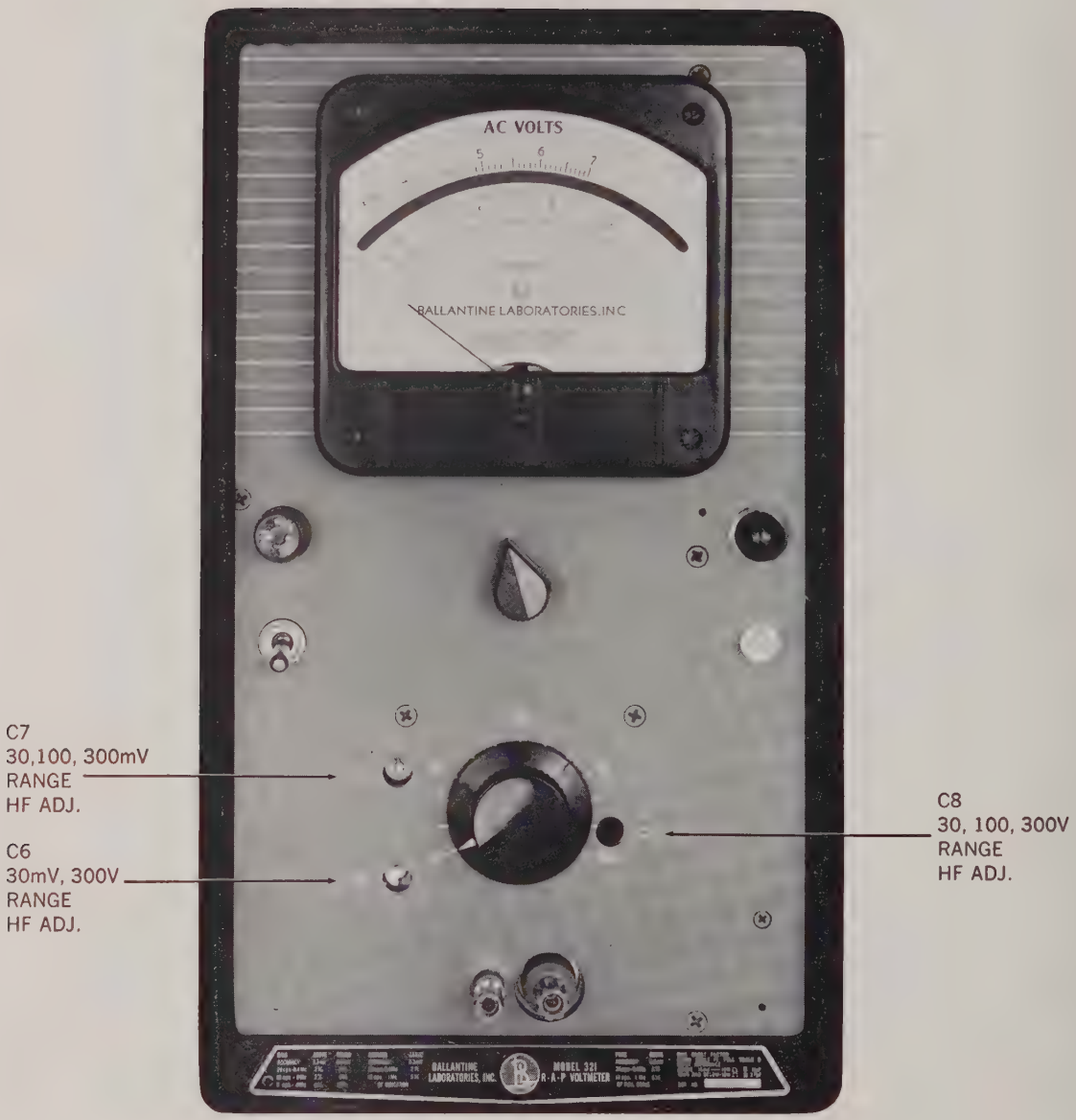


Fig. 15. Front View of Model 321 (escutcheon plate removed) Showing Location of Adjustments

7. REPLACEMENT PARTS LIST

REFER TO MODEL 321 CIRCUIT DIAGRAM, DWG. ME-2392C

B. L. Part No.	*Circuit Symbol*	*Capacitors*	*Manufacturer*
2388	C1	.033 μF, 10%, 600 V	Sprague
2255	C2	3300 pF, 5%, Type CM-20-E-332-J	Arco
2275	C3	75 pF, 1%, Type CM-15-E-750-E	Arco
2546	C4	.22 pF, ±10%, Type QC, 500 VDCW	Quality Components
2241	C5	15 pF, 5%, Type CM-15-C-150-J	Arco
2440	C6	1.2 - 3.5 pF, Type 189-1-5, 850 V	Johnson
2444	C7	2.5 - 11 pF, Type N300, Style 538-002	Erie
2441	C8	9 - 35 pF, Type N650, Style 538-002, 200 VDCW	Erie
2771	C15A	60 μF, −10%, +100%, 250 VDCW, Special	Ballantine
	C15B	40 μF, −10%, +100%, 250 VDCW, Special	Ballantine
	C15C	30 μF, −10%, +100%, 250 VDCW, Special	Ballantine
	C15D	30 μF, −10%, +100%, 250 VDCW, Special	Ballantine
2572	C16	4.7 μF, ±20%, Type 150D475X0006A2, 6 VDCW	Sprague
2362	C17	.22 μF, 5%, Type 192P, 200 V	Sprague
2232	C18	150 pF, 5%, Type CM-15-E-151-J	Arco
2098	C19	12 μF, 250 V, Special	Ballantine
2412	C20	25 - 280 pF, Special	Ballantine
2364	C21	.033 μF, 5%, Type 192P, 200 V	Sprague
2535	C22	.01 μF, 0 +100%, Type BYA-6S1, 600 VDCW	Cornell-Dubilier
2094	C23	250 μF, −10%, +100%, Type 89 D 117, 3 VDCW	Sprague
2098	C24	12 μF, 250 V, Special	Ballantine
2098	C25	12 μF, 250 V, Special	Ballantine
2097	C26	50 μF, −10%, +100%, 250 VDCW	Ballantine
2442	C30	2 - 8 pF, Type NPO, Style 538-002, 200 VDCW	Erie
2442	C31	2 - 8 pF, Type NPO, Style 538-002, 200 VDCW	Erie
2371	C35	.047 μF, 10%, Type 192P, 200 V	Sprague
2277	C36	47 pF, 5%, Type CM-15-E-470J, 500 V	Arco
2098	C37	12 μF, 250 V, Special	Ballantine
2354	C38	.15 μF, 10%, Type 192P, 200 V	Sprague
2095	C39A	100 μF, −10%, +100%, Type 89D150, 12 VDCW	Sprague
	C39B	100 μF, −10%, +100%, Type 89D150, 12 VDCW	Sprague
2354	C40	.15 μF, 10%, Type 192P, 200 V	Sprague

REPLACEMENT PARTS LIST (Continued)

REFER TO MODEL 321 CIRCUIT DIAGRAM, DWG. ME-2392C

B. L. Part No.	*Circuit Symbol*	*Capacitors*	*Manufacturer*
2098	C41	12 μF, 250 V, Special	Ballantine
2098	C42	12 μF, 250 V, Special	Ballantine
2540	C43	.005 μF, 20%, Type EGP Z5U, Style 851, 500 VDCW	Erie
2440	C44	1.2 - 3.5 pF, Type 189-1-5, 850 V	Johnson
2545	C45	.82 pF, ±10%, Type QC, 500 VDCW	Quality Components
2440	C46	1.2 - 3.5 pF, Type 189-1-5, 850 V	Johnson
2364	*C47	.033 μF, 5%, Type 192P, 200 V	Sprague
2371	*C48	.047 μF, 10%, Type 192P, 200 V	Sprague
2770	C50A	180 μF, −10%, +100%, Type DFP, 200 VDCW	Sprague
	C50B	180 μF, −10%, +100%, Type DFP, 200 VDCW	Sprague
	C50C	20 μF, −10%, +100%, Type DFP, 200 VDCW	Sprague
	C50D	20 μF, −10%, +100%, Type DFP, 200 VDCW	Sprague
	C51	.02 μF, part of T2	Ballantine
	C52	.02 μF, part of T2	Ballantine
2096	C55	50 μF, −10%, +75%, Type 30D170A1, 15 VDCW	Sprague
2096	C56	50 μF, −10%, +75%, Type 30D170A1, 15 VDCW	Sprague
2555	C57	.02 μF, ±20%, Type Y5V, Style 841, 500 VDCW	Erie
2772	C60A	30 μF, −10%, +50%, Type DFP, 450 VDCW	Sprague
	C60B	30 μF, −10%, +50%, Type DFP, 450 VDCW	Sprague
	C60C	20 μF, −10%, +50%, Type DFP, 450 VDCW	Sprague
	C60D	20 μF, −10%, +50%, Type DFP, 450 VDCW	Sprague
2792	C61A	1500 μF, −10%, +150%, Type DFP, 15 VDCW	Sprague
	C61B	1500 μF, −10%, +150%, Type DFP, 15 VDCW	Sprague
2020	C62	3000 μF, −10%, +150%, Type DFP, 10 VDCW	Sprague
2555	C70	.02 μF, ±20%, Type Y5V, Style 841, 500 VDCW	Erie
2555	C71	.02 μF, ±20%, Type Y5V, Style 841, 500 VDCW	Erie
2088	C80	50 μF, −10%, +75%, Type 30D186, 25 V	Sprague
8100	C81	1 μF, 20%, Type 149P10501, 100 V	Sprague
2044	C82	1000 μF, Type FP, 15 V	Magnavox

*In some instruments the component listed may not be used at all or its value may differ from the value shown.

REPLACEMENT PARTS LIST (Continued)

REFER TO MODEL 321 CIRCUIT DIAGRAM, DWG. ME-2392C

B. L. Part No.	*Circuit Symbol*	*Resistors*	*Manufacturer*
1276	R1	5.6 ohms, 5%, Type GB	Allen-Bradley
1108	R2	180 ohms, 5%, Type EB	Allen-Bradley
1072	R3	39 ohms, 5%, Type EB	Allen-Bradley
2728	R4(1)	10,000,000 ohms, 1%, Type PT-70	Pyrofilm
1015	R5	470,000 ohms, 5%, Type EB	Allen-Bradley
2729	R6(1)	337,600 ohms, 1%, Type PT-500	Pyrofilm
2730	R7(1)	9,703 ohms, 1%, Type PT-500	Pyrofilm
2731	R8(1)	316.5 ohms, 1%, Type PT-500	Pyrofilm
1463	R15	10,000,000 ohms, 1%, Type CPX-1	Aerovox
1061	R16	510 ohms, 5%, Type EB	Allen-Bradley
1061	R17	510 ohms, 5%, Type EB	Allen-Bradley
1687	R18	50,000 ohms, 1%, Type N-20	Corning
1054	R19	2,000 ohms, 5%, Type EB	Allen-Bradley
2734	R20	15 ohms, 1%, Type CPX-½	Aerovox
1040	R21	20,000 ohms, 5%, Type EB	Allen-Bradley
1010	R22	1,000,000 ohms, 5%, Type EB	Allen-Bradley
1246	R23	220 ohms, 10%, Type CB	Allen-Bradley
1034	R24	39,000 ohms, 5%, Type EB	Allen-Bradley
2620	R25	21 ohms, 1%, Type CPX-½	Aerovox
1690	R26	20,000 ohms, 5%, Type C-42S	Corning
1686	R27	3,900 ohms, 5%, Type C-20	Corning
1064	R28	220 ohms, 5%, Type EB	Allen-Bradley
1935	R29	250 ohms, 30%, Type UPM-45	Chicago Telephone
1036	R30	33,000 ohms, 5%, Type EB	Allen-Bradley
1012	R31	750,000 ohms, 5%, Type EB	Allen-Bradley
1246	R32	220 ohms, 10%, Type CB	Allen-Bradley
1034	R33	39,000 ohms, 5%, Type EB	Allen-Bradley
1690	R34	20,000 ohms, 5%, Type C-42S	Corning
1330	R35	3,000 ohms, 1%, Type CPX-½	Aerovox
1066	R36	160 ohms, 5%, Type EB	Allen-Bradley
1041	R37	18,000 ohms, 5%, Type EB	Allen-Bradley
1040	R38	20,000 ohms, 5%, Type EB	Allen-Bradley
1327	R40(2)	5,000 ohms, ±1%, Type CPX-½	Aerovox
2732	R42(2)	1,580 ohms, ±1%, Type CPX-½	Aerovox
2733	R42(2)	731 ohms, ±1%, Type CPX-½	Aerovox

(1) Resistors R4, R6, R7, R8 are part of a matched set and must be purchased as Set No. 1571.
(2) Resistors R40, R41, R42 are part of a matched set and must be ordered as Part No. 1568.

REPLACEMENT PARTS LIST (Continued)

REFER TO MODEL 321 CIRCUIT DIAGRAM, DWG. ME-2392C

B. L. Part No.	*Circuit Symbol*	*Resistors*	*Manufacturer*
1061	R45	510 ohms, 5%, Type EB	Allen-Bradley
1007	R46	2,000,000 ohms, 5%, Type EB	Allen-Bradley
1358	R47	60 ohms, 7%, Type CPX-½	Aerovox
1003	*R48	5,100,000 ohms, 5%, Type EB	Allen-Bradley
1688	R49	25,000 ohms, 2%, Type C-32	Corning
1054	R50	2,000 ohms, 5%, Type EB	Allen-Bradley
1749	R51	100 ohms, 1%, Type RLS-1B	Dahlohm
1704	R52	156 ohms, 1%, Type RLS-1B	Dahlohm
1015	R53	470,000 ohms, 5%, Type EB	Allen-Bradley
1015	R54	470,000 ohms, 5%, Type EB	Allen-Bradley
1085	R55	120,000 ohms, 5%, Type EB	Allen-Bradley
1246	R56	220 ohms, 10%, Type CB	Allen-Bradley
1246	R57	220 ohms, 10%, Type CB	Allen-Bradley
7246	R58	6,000 ohms, 2%, Type C-32	Corning
7246	R59	6,000 ohms, 2%, Type C-32	Corning
1060	R60	620 ohms, 5%, Type EB	Allen-Bradley
1060	R61	620 ohms, 5%, Type EB	Allen-Bradley
1692	R62	3,600 ohms, 5%, Type C-42S	Corning
7247	R63	27,000 ohms, 2%, Type C-32	Corning
7247	R64	27,000 ohms, 2%, Type C-32	Corning
1680	R65	20,000 ohms, 1%, Type N-20	Corning
1680	R66	20,000 ohms, 1%, Type N-20	Corning
1683	R67	600 ohms, 1%, Type N-20	Corning
1711	R68	10,000 ohms, 1%, Type RS-5	Dahlohm
1691	R69	10,000 ohms, 5%, Type C-42S	Corning
1100	R70	1,200 ohms, 5%, Type EB	Allen-Bradley
1831	R71	15,000 ohms, 10%, Type 43-15 WW Pot	Clarostat
1100	R72	1,200 ohms, 5%, Type EB	Allen-Bradley
1121	*R73	5,600 ohms, 5%, Type EB	Allen-Bradley
1003	*R74	5,100,000 ohms, 5%, Type EB	Allen-Bradley
1036	R75	33,000 ohms, 5%, Type EB	Allen-Bradley
1682	R76	1,000 ohms, 1%, Type N-20	Corning
1934	R77	400 ohms, 20%, Type UPM-45	Chicago Telephone
1681	R78	4,700 ohms, 1%, Type N-20	Corning

*In some instruments the component listed may not be used at all or its value may differ from the value shown.

REPLACEMENT PARTS LIST (Continued)

REFER TO MODEL 321 CIRCUIT DIAGRAM, DWG. ME-2392C

B. L. Part No.	*Circuit Symbol*	*Resistors*	*Manufacturer*
1680	R79	20,000 ohms, 1%, Type N-20	Corning
1057	R80	1,000 ohms, 5%, Type EB	Allen-Bradley
7257	R81	100,000 ohms, 1%, Type MF7C	Electra
7250	R82	10,400,000 ohms, 1%, Type MF72C	Electra
7251	R83	7,230,000 ohms, 1%, Type MF72C	Electra
7252	R84	3,480,000 ohms, 1%, Type MF7C	Electra
7253	R85	1,550,000 ohms, 1%, Type MF7C	Electra
7254	R86	762,000 ohms, 1%, Type MF7C	Electra
7255	R87	341,000 ohms, 1%, Type MF7C	Electra
7256	R88	138,000 ohms, 1%, Type MF7C	Electra
7262	R89	40,500 ohms, 1%, Type MF7C	Electra
1918	R90	200,000 ohms, 20%, Type UPM-45	Chicago Telephone
7259	R91	78,500 ohms, 1%, Type MF7C	Electra
7258	R92	94,400 ohms, 1%, Type MF7C	Electra
7260	R93	67,500 ohms, 1%, Type MF7C	Electra
7261	R94	45,600 ohms, 1%, Type MF7C	Electra
7263	R95	34,000 ohms, 1%, Type MF7C	Electra
7264	R96	23,200 ohms, 1%, Type MF7C	Electra
7265	R97	14,600 ohms, 1%, Type MF7C	Electra
7266	R98	7,500 ohms, 1%, Type MF7C	Electra
1063	R99	300 ohms, 5%, Type EB	Allen-Bradley
1065	R103	200 ohms, 5%, Type EB	Allen-Bradley
1064	R104	220 ohms, 5%, Type EB	Allen-Bradley
1652	R105	500 ohms, 5%, Type 452-E-5015	Sprague
1707	R106	1,800 ohms, 5%, Type 452-E-1825	Sprague
1585	R107	10 ohms, 5%, Type BWH	IRC
6163	R108	5.6 ohms, 5%, Type BWH	IRC
1718	R109	1,500 ohms, 5%, Type 458-E-1525	Sprague
1040	R110	20,000 ohms, 5%, Type EB	Allen-Bradley
1679	R111	100,000 ohms, 1%, Type N-20	Corning
1689	R112	33,000 ohms, 5%, Type C-42S	Corning
1842	R120	3,000 ohms, ±10%, Type PM-AW	CTS
7214	R121	590 ohms, 1%, Type N-20	Corning
7246	R122	6,000 ohms, 2%, Type C-32	Corning

REPLACEMENT PARTS LIST (Continued)

REFER TO MODEL 321 CIRCUIT DIAGRAM, DWG. ME-2392C

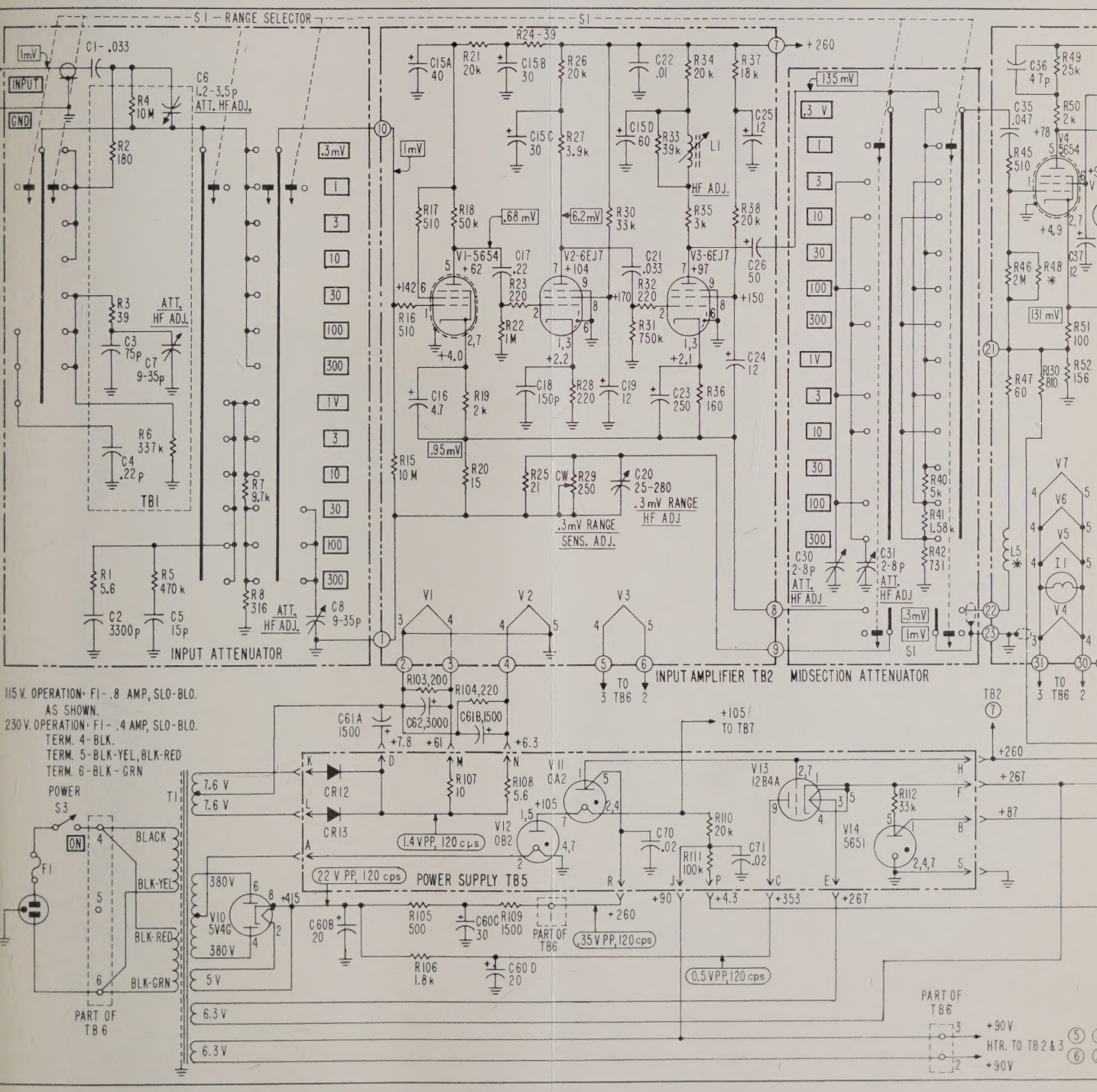
B. L. Part No.	*Circuit Symbol*	*Resistors*	*Manufacturer*
1843	R123	400 ohms, ±10%, Type PM-AW	CTS
1844	R124	100 ohms, ±10%, Type PM-AW	CTS
7216	R125	487 ohms, 1%, Type N-20	Corning
1676	R126	85 ohms, 5%, Type C-20	Corning
1843	R127	400 ohms, ±10%, Type PM-AW	CTS
1681	R128	4,700 ohms, 1%, Type N-20	Corning
7221	*R129	309 ohms, 1%, Type N-20	Corning
7229	R130	810 ohms, 1%, Type N-20	Corning
7214	R131	590 ohms, 1%, Type N-20	Corning
1579	RT1	Thermistor, 6,300 ohms, ±10%, Type 36S1	Victory Eng.
1154	RT2	Thermistor, 100 ohms, ±10%, Type 21E26	Victory Eng.
		Other Components	
5576	CR1, 2	Diode, Germanium, Type 1N618	Amperex
5562	CR3	Diode, Silicon, Type SG22, or Type 1N816	
3144	CR4	Diode, Type S53G	Transitron
5555	CR5, 6	Diode, Type T 13G	Transitron
5555	CR7, 8	Diode, Type T 13G, or Diode, Type T 14G	Transitron
5563	CR9, 10	Diode, Type T 14G, or Diode, Type T 13G	Transitron
5563	CR11	Diode, Type T 14G, or Diode, Type T 13G	Transitron
7921	CR12, 13	Rectifier, Silicon Type 36591	RCA
7904	CR14	Diode, Zener, Type PG961A	Hoffmann
7901	CR15	Diode, Type 1E6.8Z	Computer Diode
7921	CR16	Rectifier, Silicon Type 36591	RCA
2804	F1	Fuse, 1.2 amp, Type 3AG Slo-Blo	Littelfuse
3007	L1	Coil, Special	Ballantine
3069	L2	L. F. Choke, Special	Ballantine
3068	L5	Inductor, Special	Ballantine
3190	M1	Meter, Taut Band, Special	Ballantine
3061	T1	Transformer, Power	Ballantine
3060	T2	Transformer, Output	Ballantine

*For Rack Versions only.

REPLACEMENT PARTS LIST (Continued)

REFER TO MODEL 321 CIRCUIT DIAGRAM, DWG. ME-2392C

B.L. Part No.	*Circuit Symbol*	*Other Components*	*Manufacturer*
3126	V1, 4	Tube, Type 5654	General Electric
5593	V2, 3, 5, 6	Tube, Type 6EJ7	Amperex
5592	V7	Tube, Type 8223, or 6DJ8	Siemens or Amperex
3138	V8, 9, 15	Lamp, Type NE-2	General Electric
3148	V10	Tube, Type 5V4G	RCA or General Electric
3106	V11	Tube, Type OA2	RCA
3128	V12	Tube, Type OB2	RCA
5569	V13	Tube, Type 12G4A	RCA
3117	V14	Tube, Type 5651	Raytheon
5592	V15	Tube, Type 6DJ8	Amperex or Sylvania
3138	V16	Lamp, Type NE-2	General Electric



CAPACITORS - NOT MARKED — MICROFARADS (10^{-6} F)
P — PICOFARADS (10^{-12} F)
RESISTORS - NOT MARKED — OHM (Ω)
K — KILOHMS (10^{3} Ω)
M — MEGOHMS (10^{6} Ω)
VOLTAGES - NOT MARKED — VOLTS (V)
mV — MILLIVOLTS (10^{-3} V)

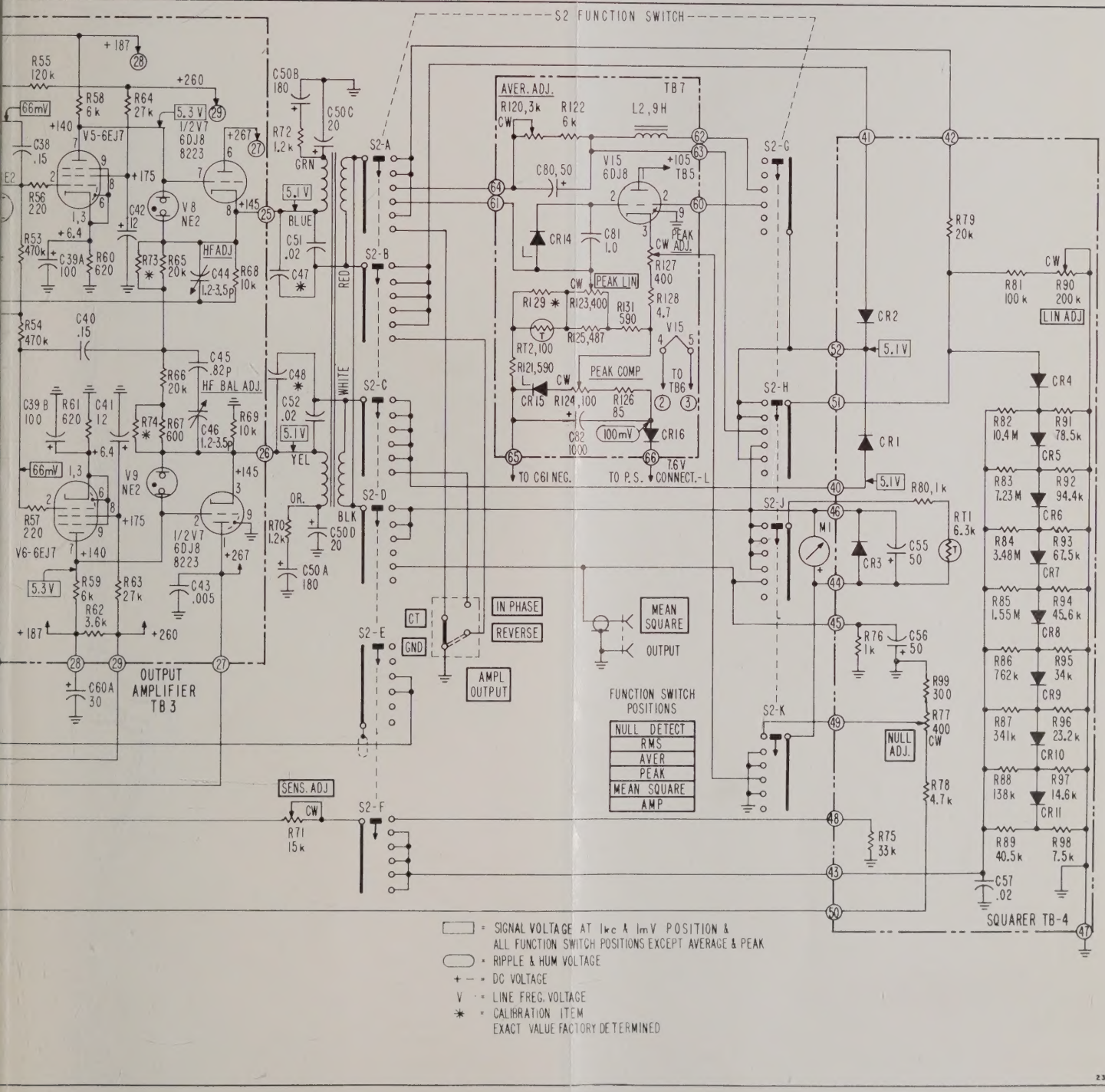


Fig. 16. Schematic of Model 321 True RMS/Average/Peak Voltmeter
Drawing No. ME-2392C

BALLANTINE LABORATORIES, INC.
BOONTON, N. J.